



US008605194B2

(12) **United States Patent**  
**Kawai et al.**

(10) **Patent No.:** **US 8,605,194 B2**  
(45) **Date of Patent:** **\*Dec. 10, 2013**

(54) **VIBRATING DEVICE AND IMAGE EQUIPMENT HAVING THE SAME**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 246 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/043,701**

(22) Filed: **Mar. 9, 2011**

(65) **Prior Publication Data**

US 2011/0261246 A1 Oct. 27, 2011

(30) **Foreign Application Priority Data**

Apr. 26, 2010 (JP) ..... 2010-101495

(51) **Int. Cl.**  
**G02B 13/16** (2006.01)  
**H04N 5/225** (2006.01)

(52) **U.S. Cl.**  
USPC ..... **348/335**; 348/241; 348/374

(58) **Field of Classification Search**  
USPC ..... 348/335, 340, 342, 374  
See application file for complete search history.

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filed: Mar. 8, 2011.

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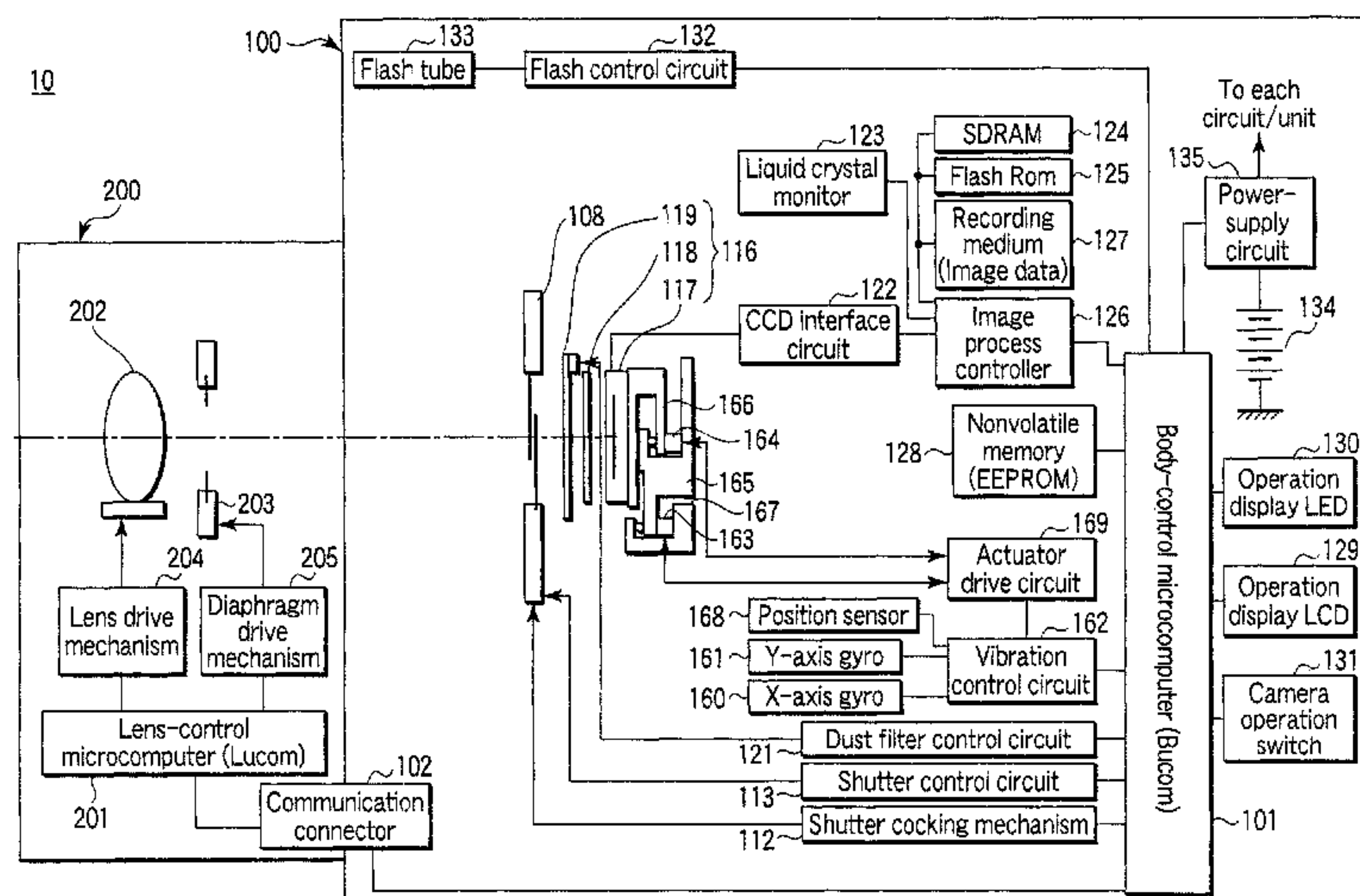
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(57) **ABSTRACT**

A dust-screening member is shaped like a plate as a whole, and has at least one side that is symmetric with respect to a virtual axis on a surface of the member. A vibrating member is adjacent to one side of the dust-screening member, arranged on the surface along the one side, and configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to the surface. A drive unit is configured to drive the vibrating member to produce the vibration on the surface, such that peak ridges of the vibration form a closed loop and an area including a center of the closed loop is surrounded by a node area having almost no vibrational amplitude.

**14 Claims, 17 Drawing Sheets**



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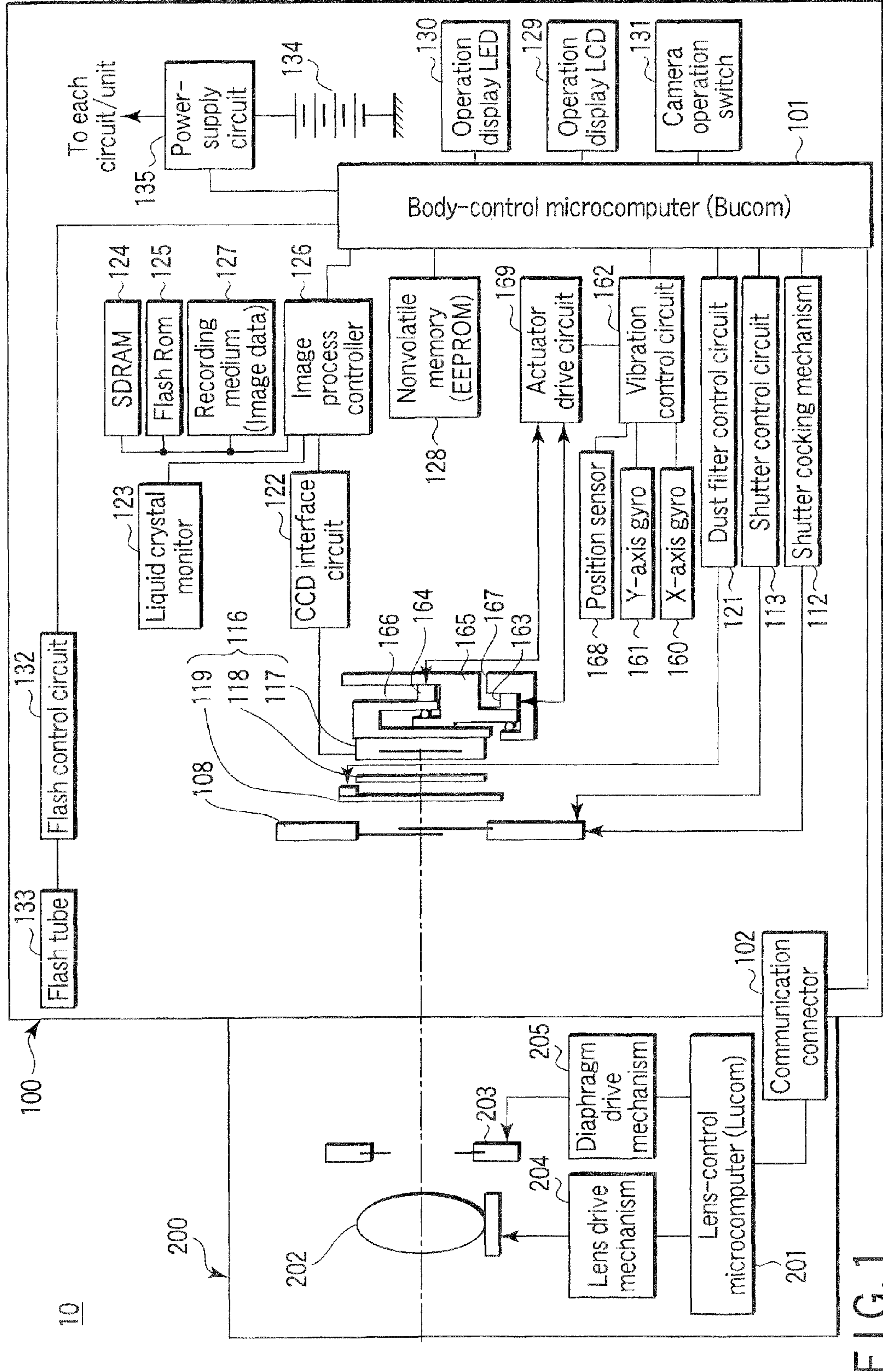


FIG. 1



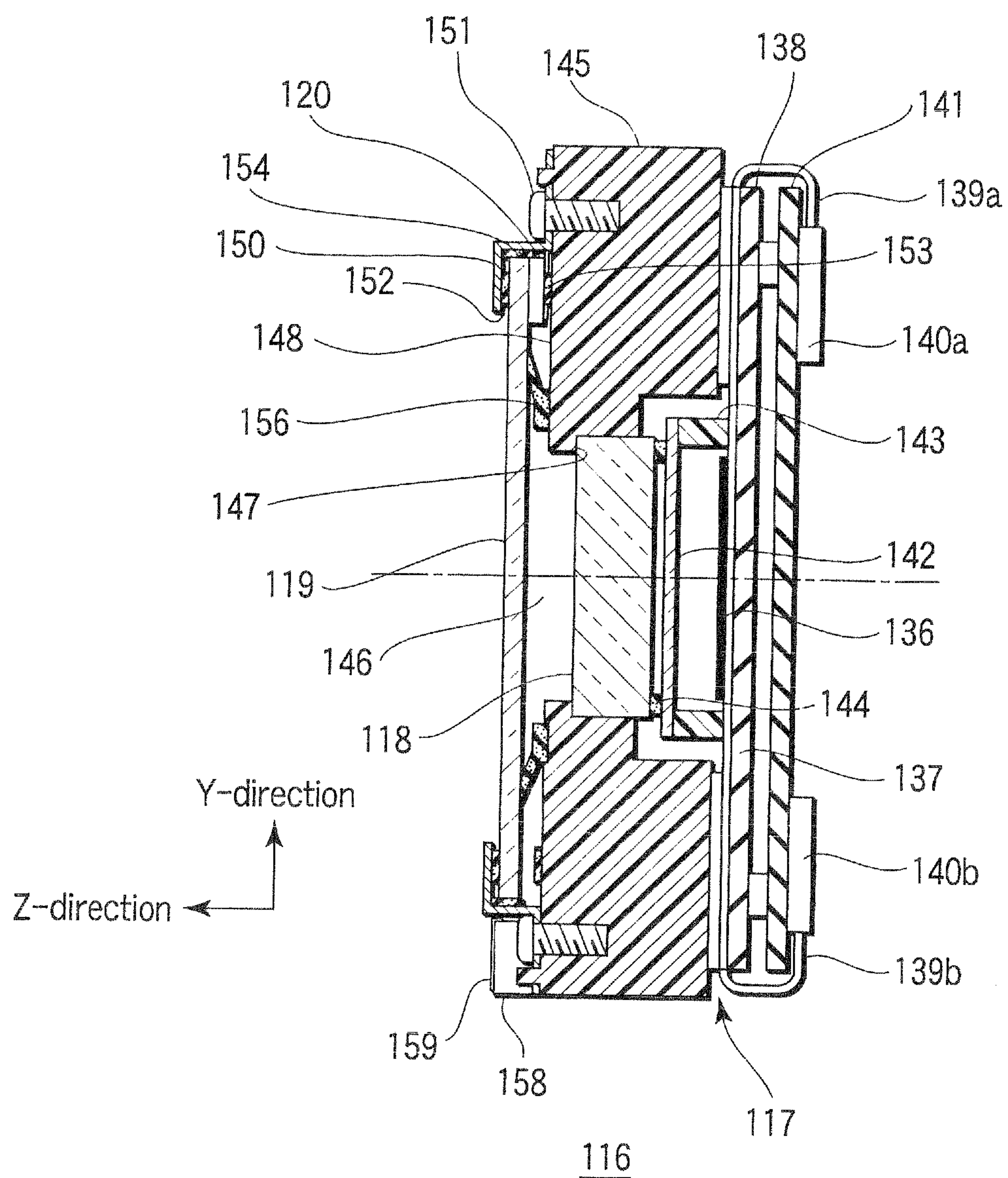


FIG. 2A

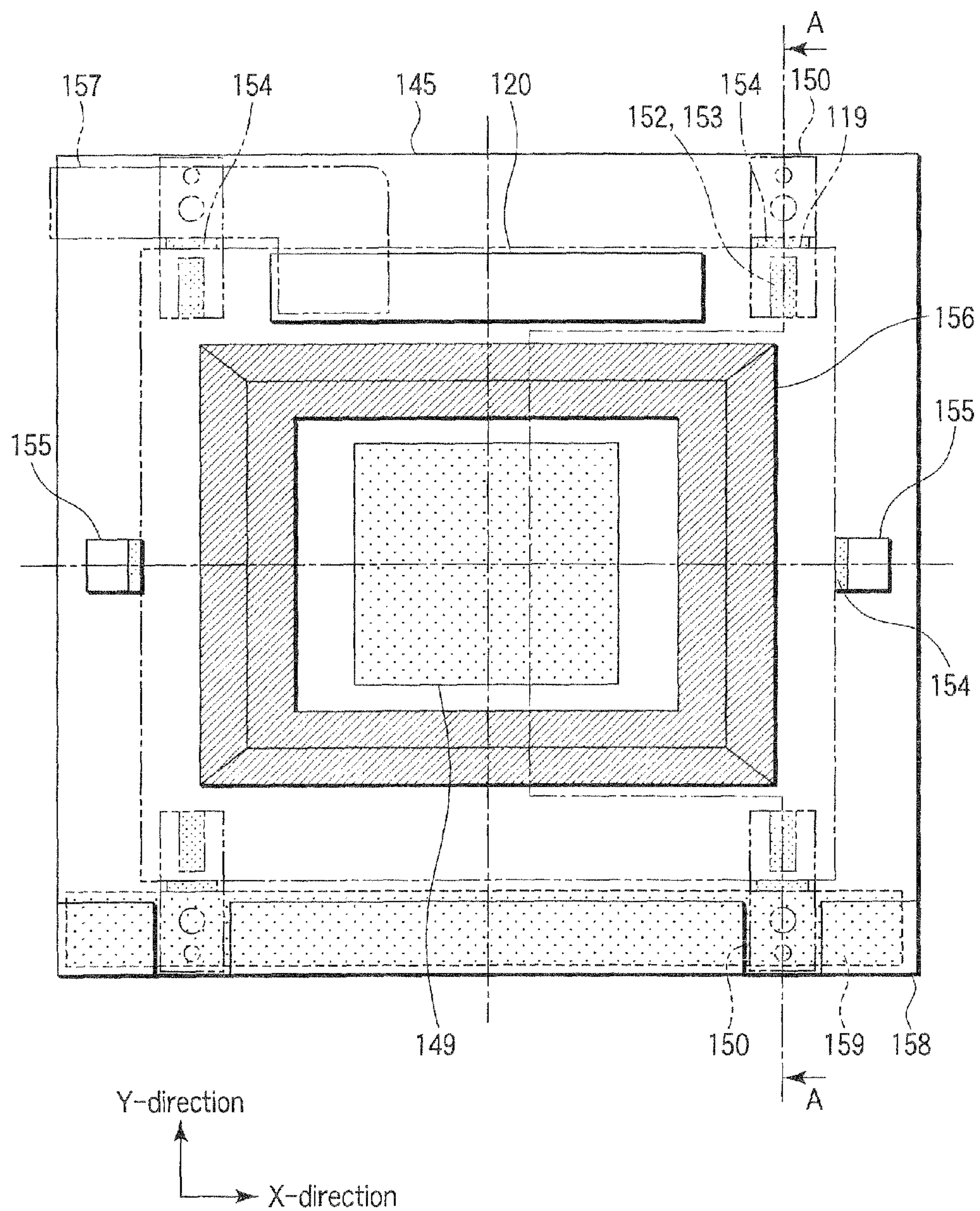


FIG. 2B

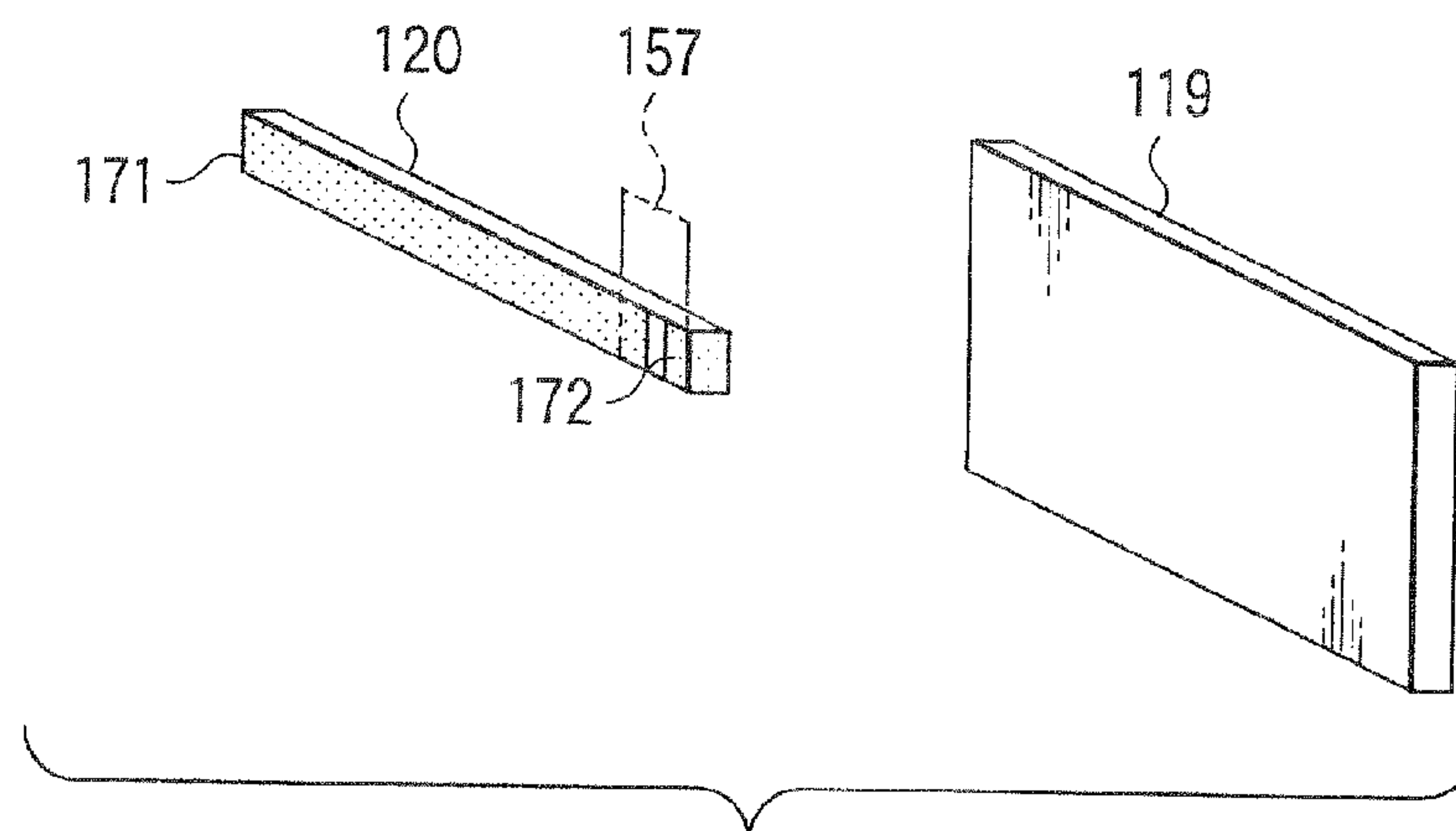


FIG. 3

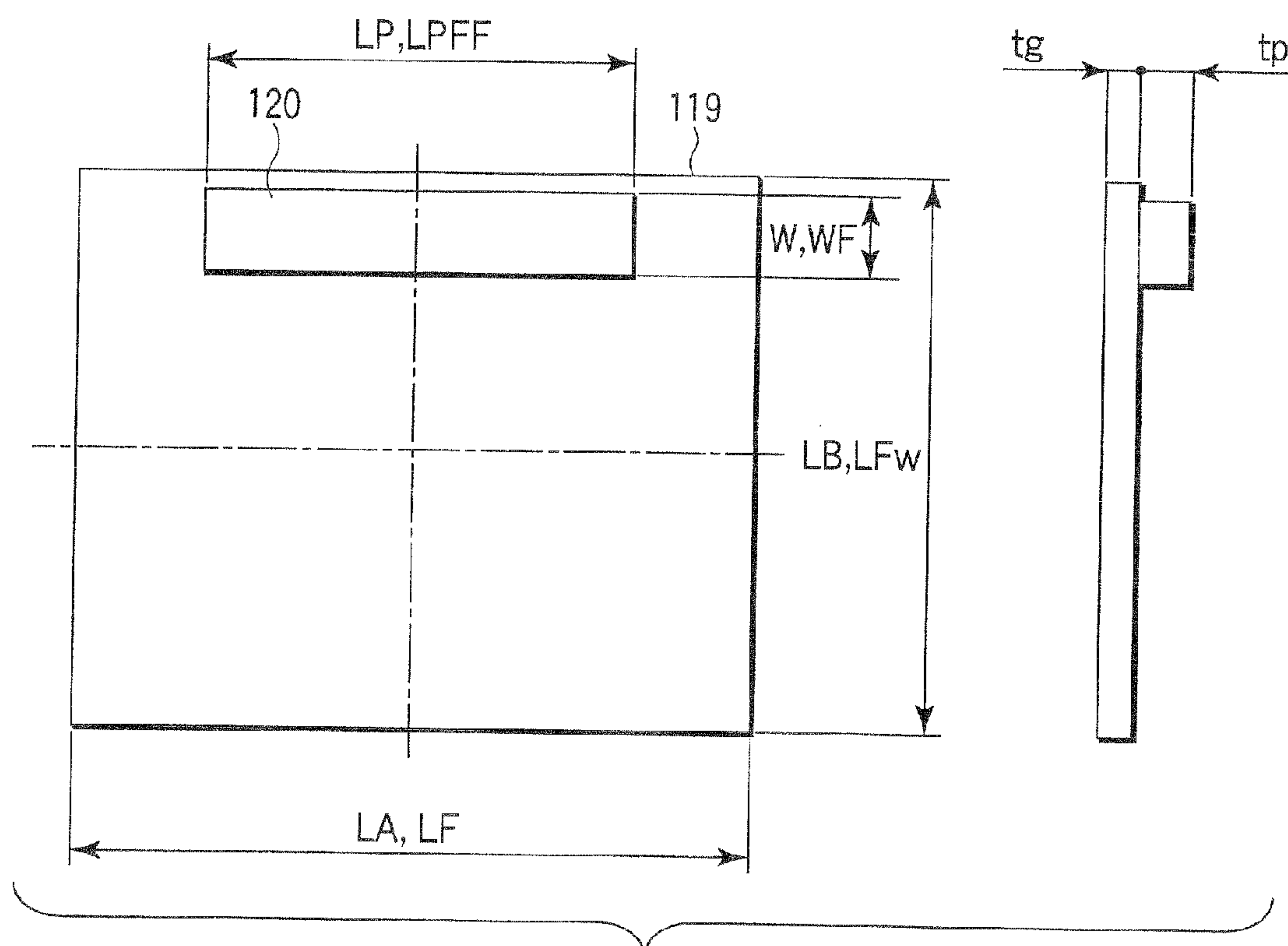


FIG. 5



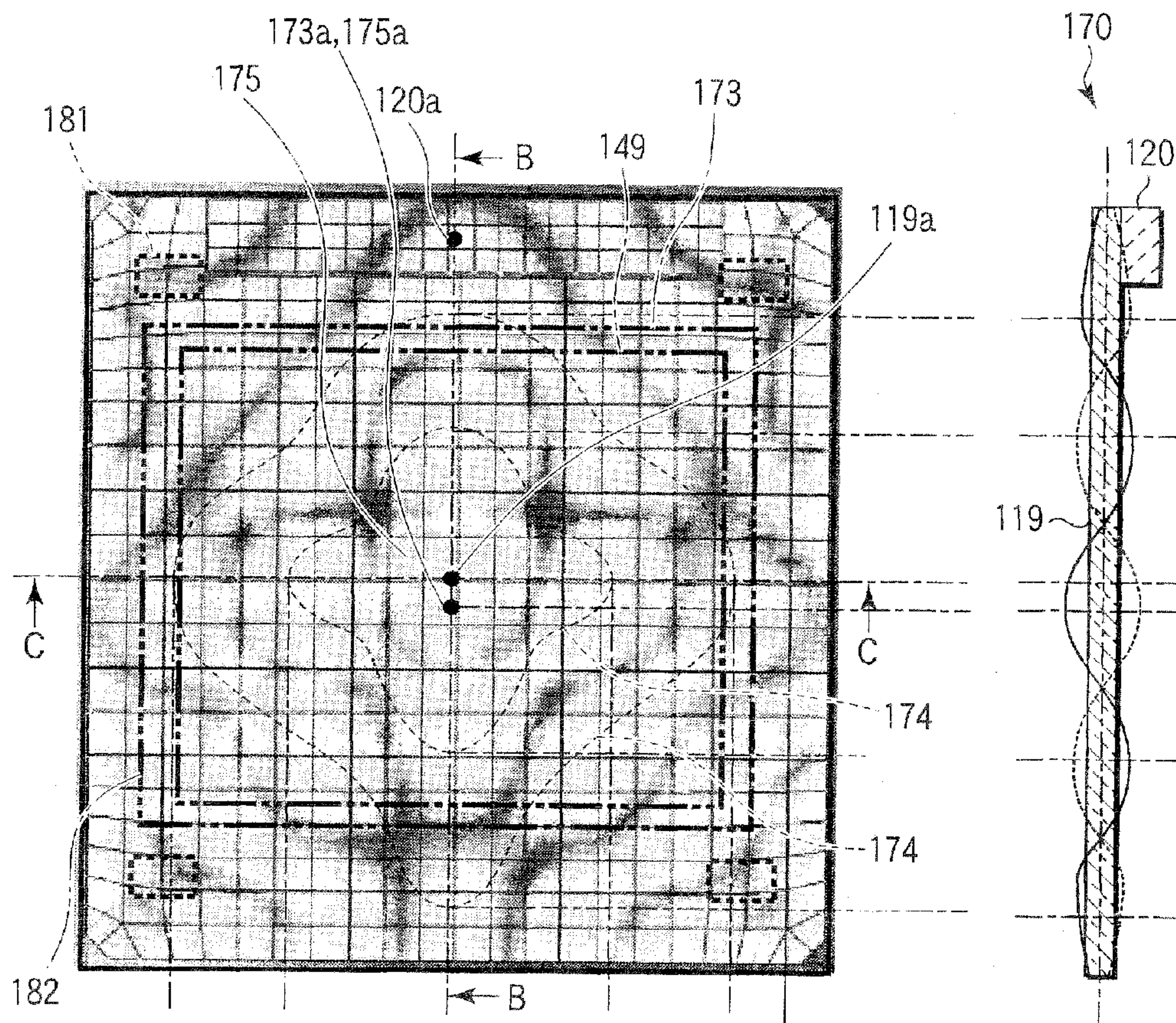


FIG. 4A

FIG. 4B

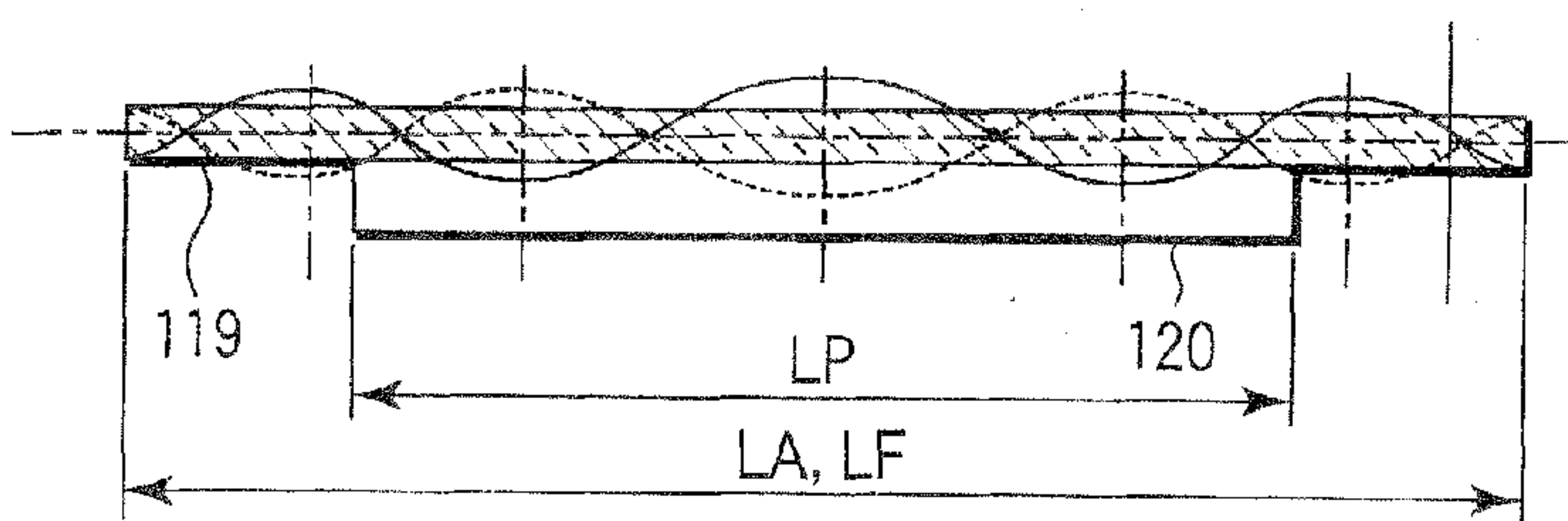
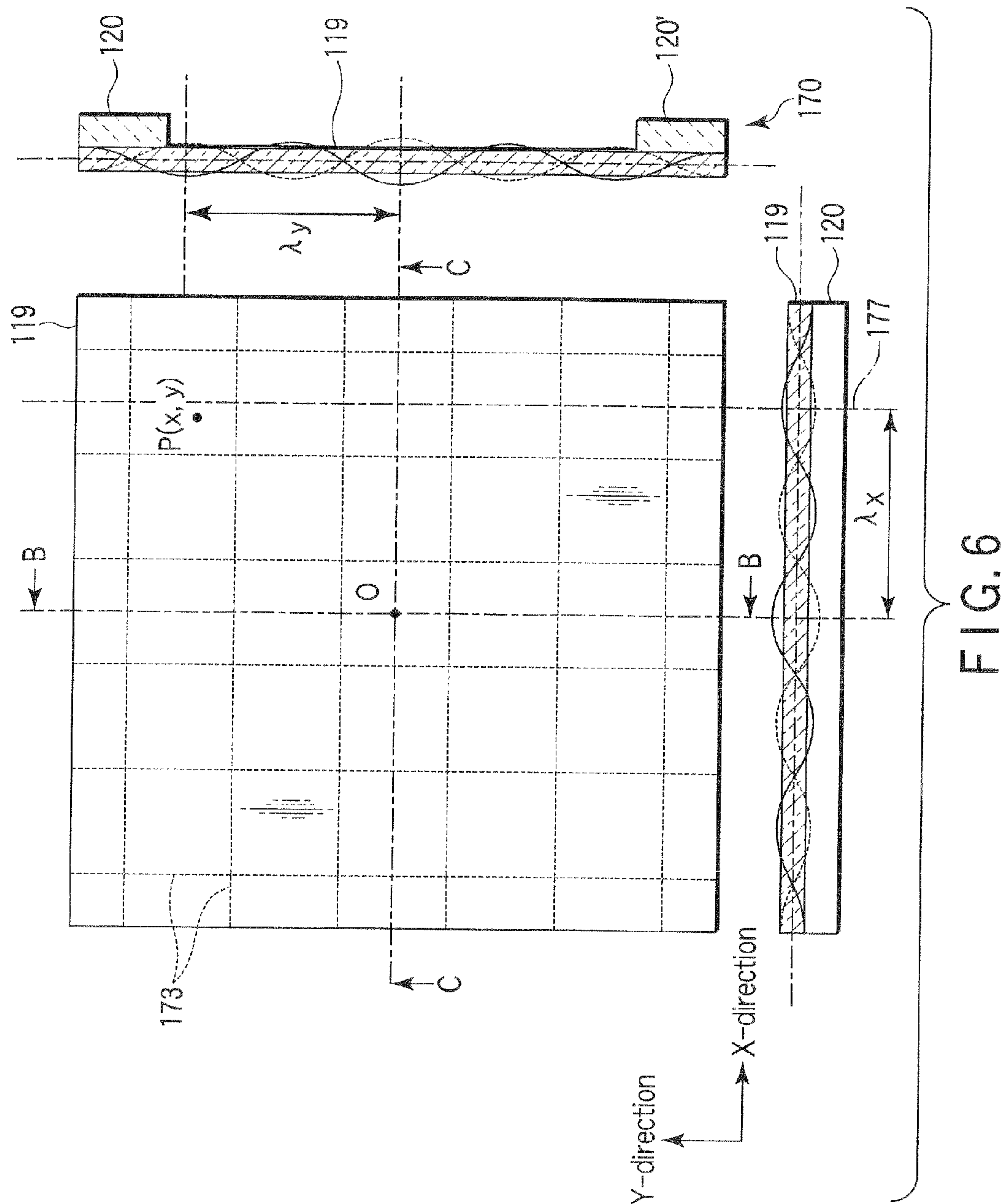


FIG. 4C





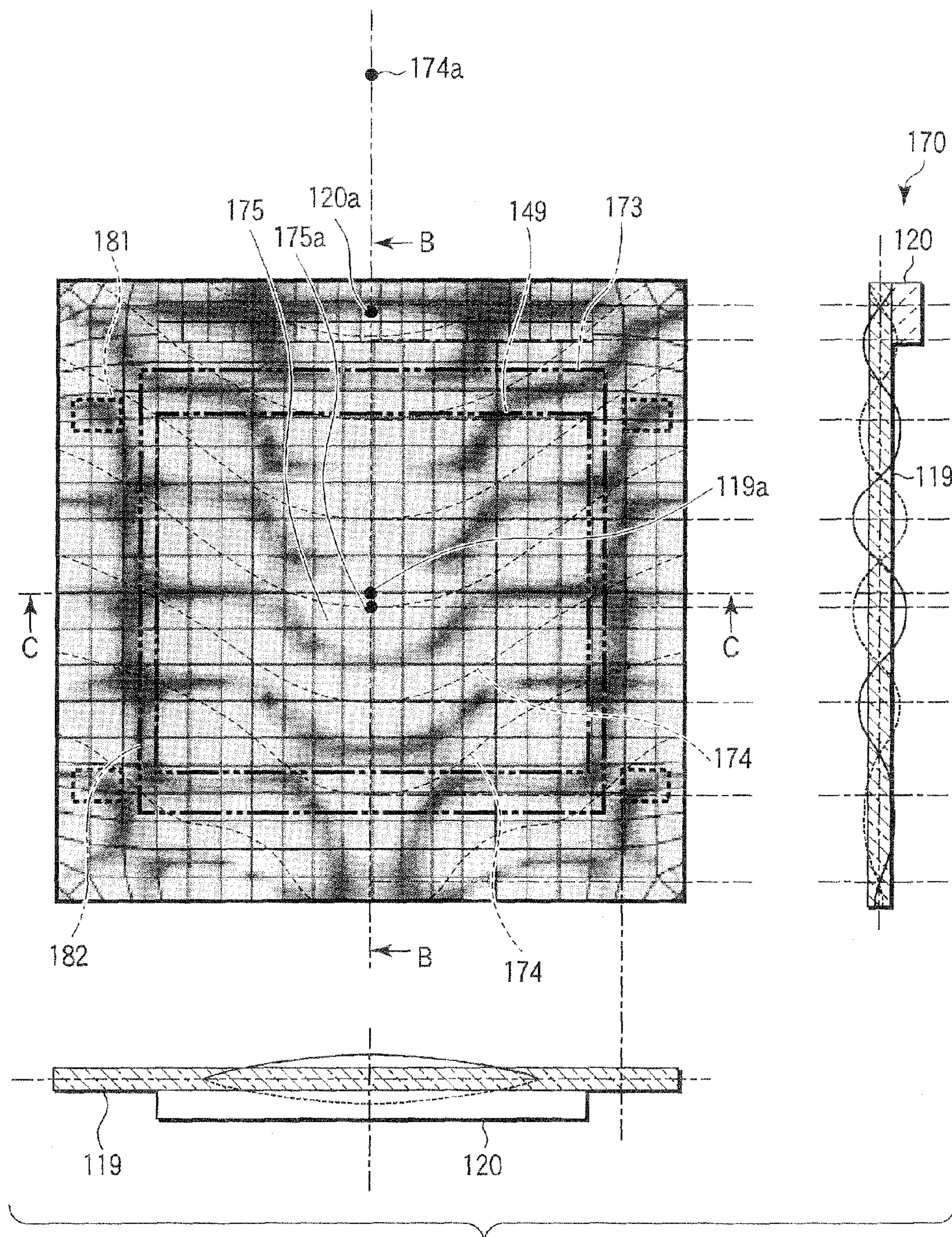


FIG. 7



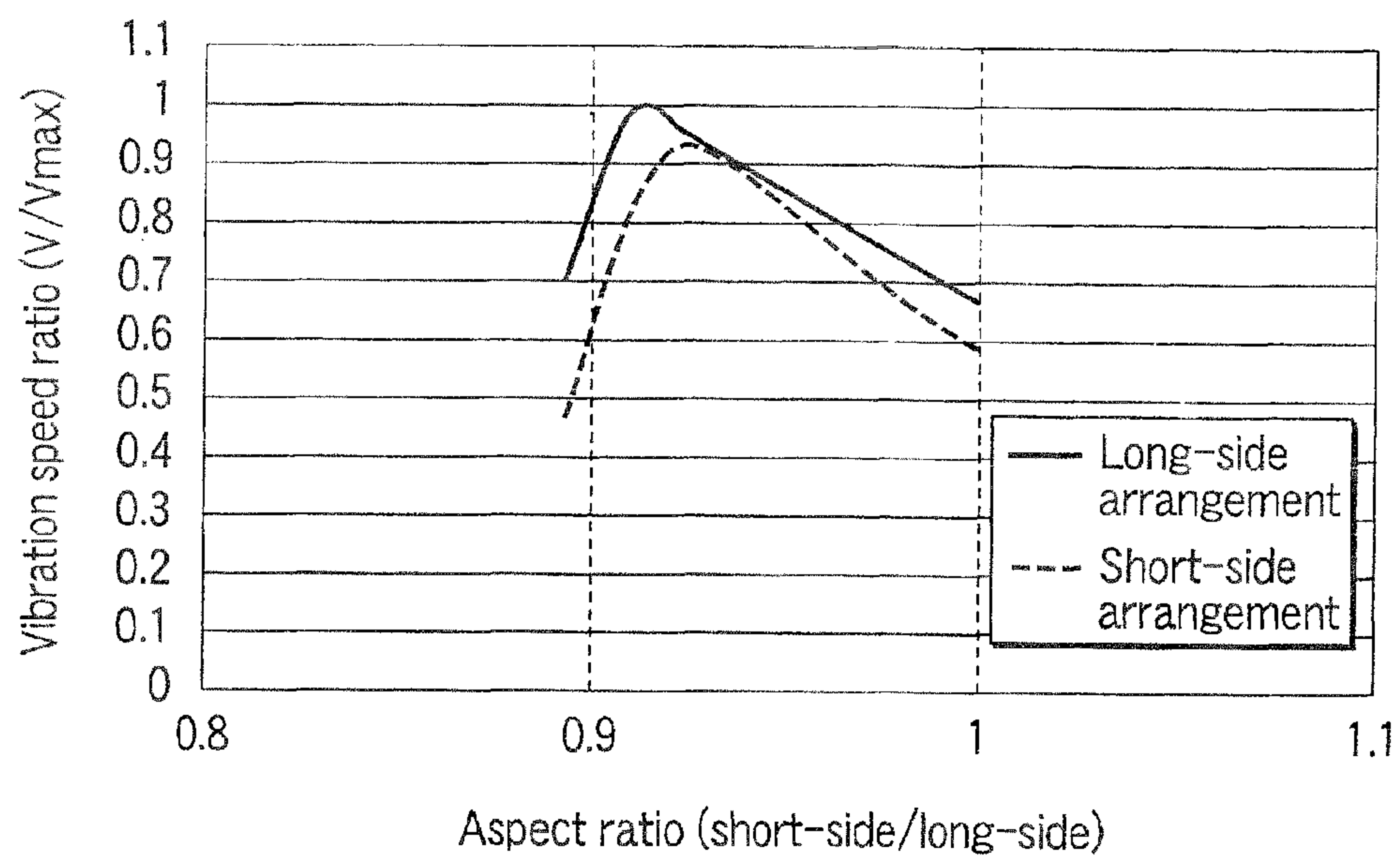


FIG. 8

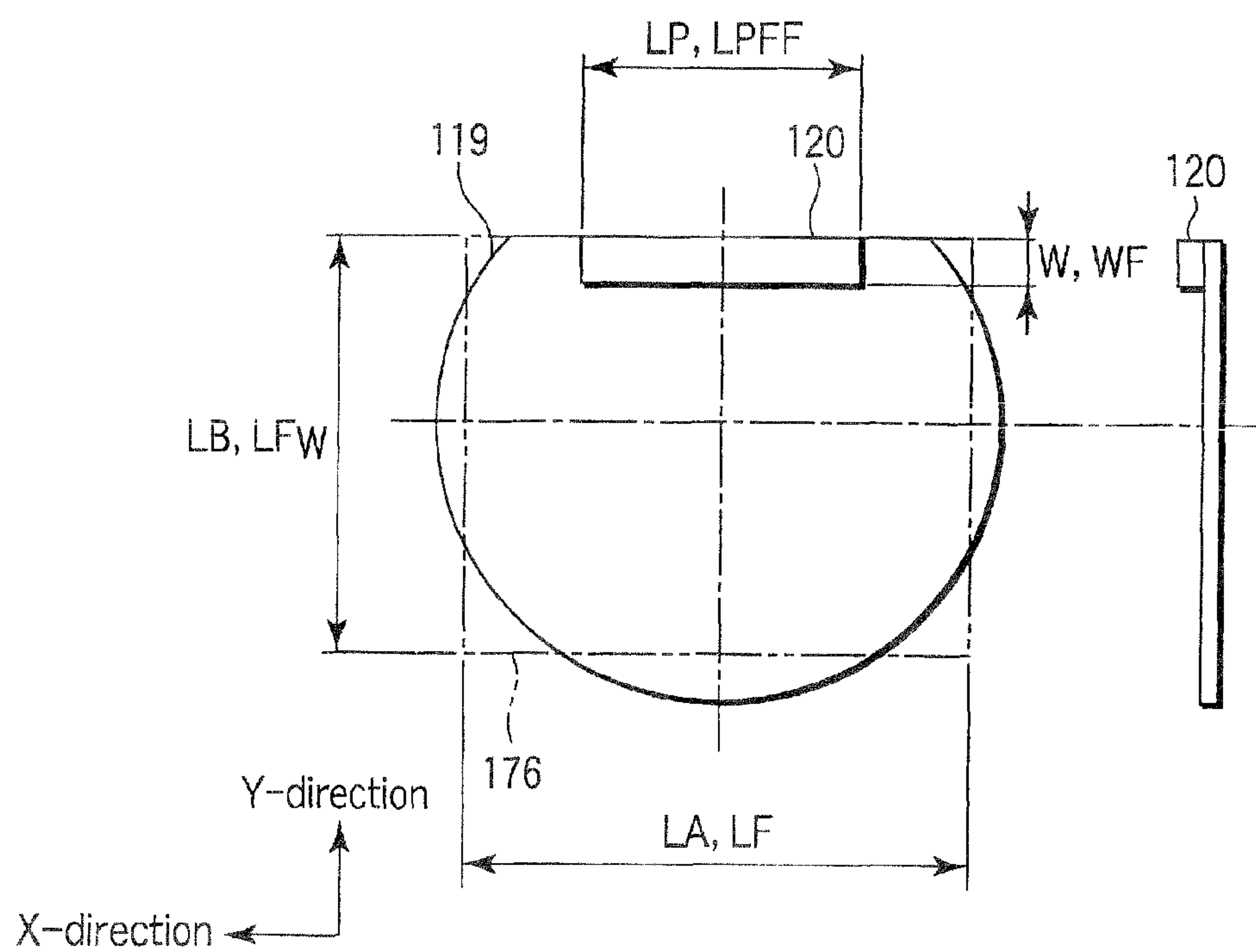


FIG. 9



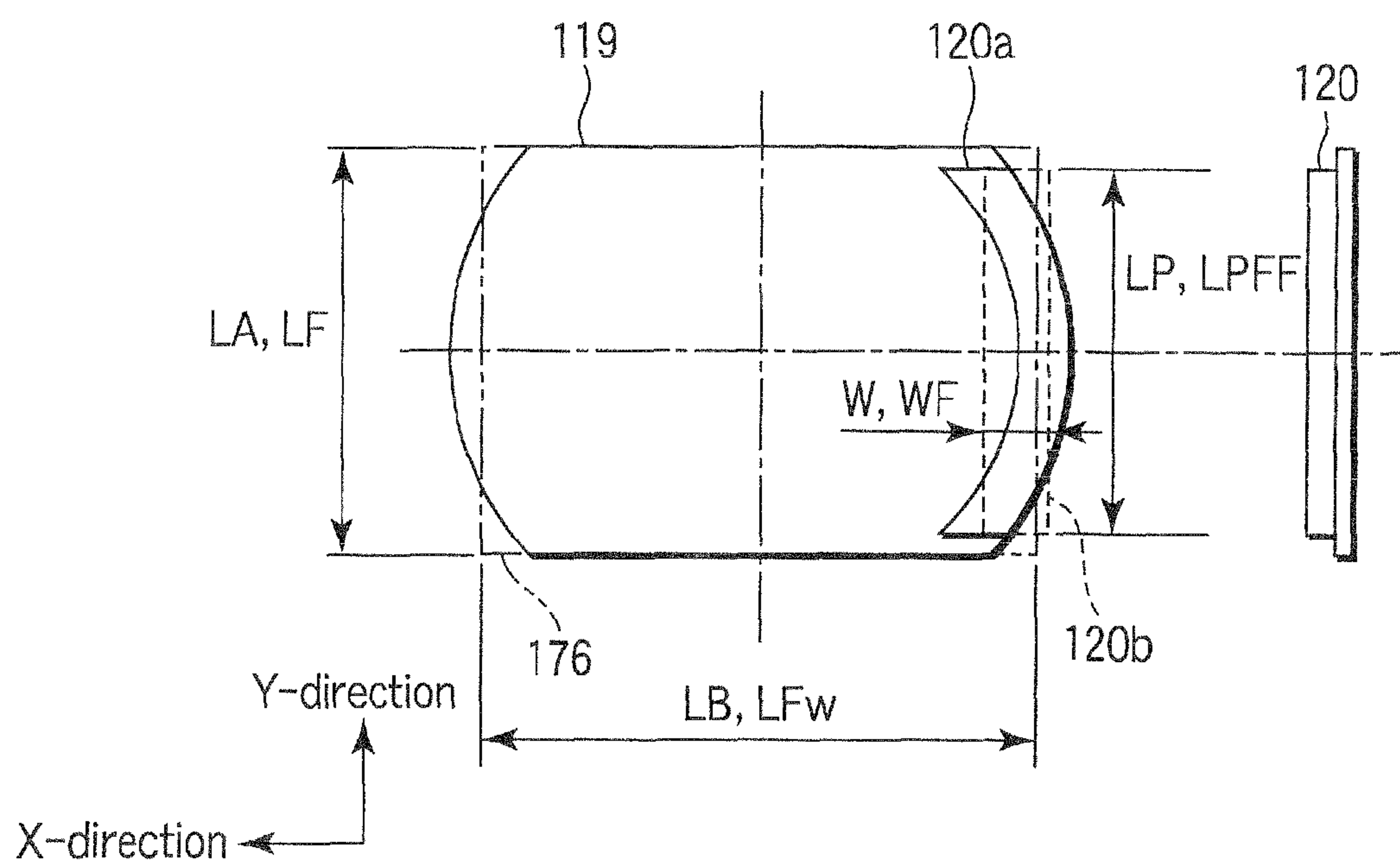
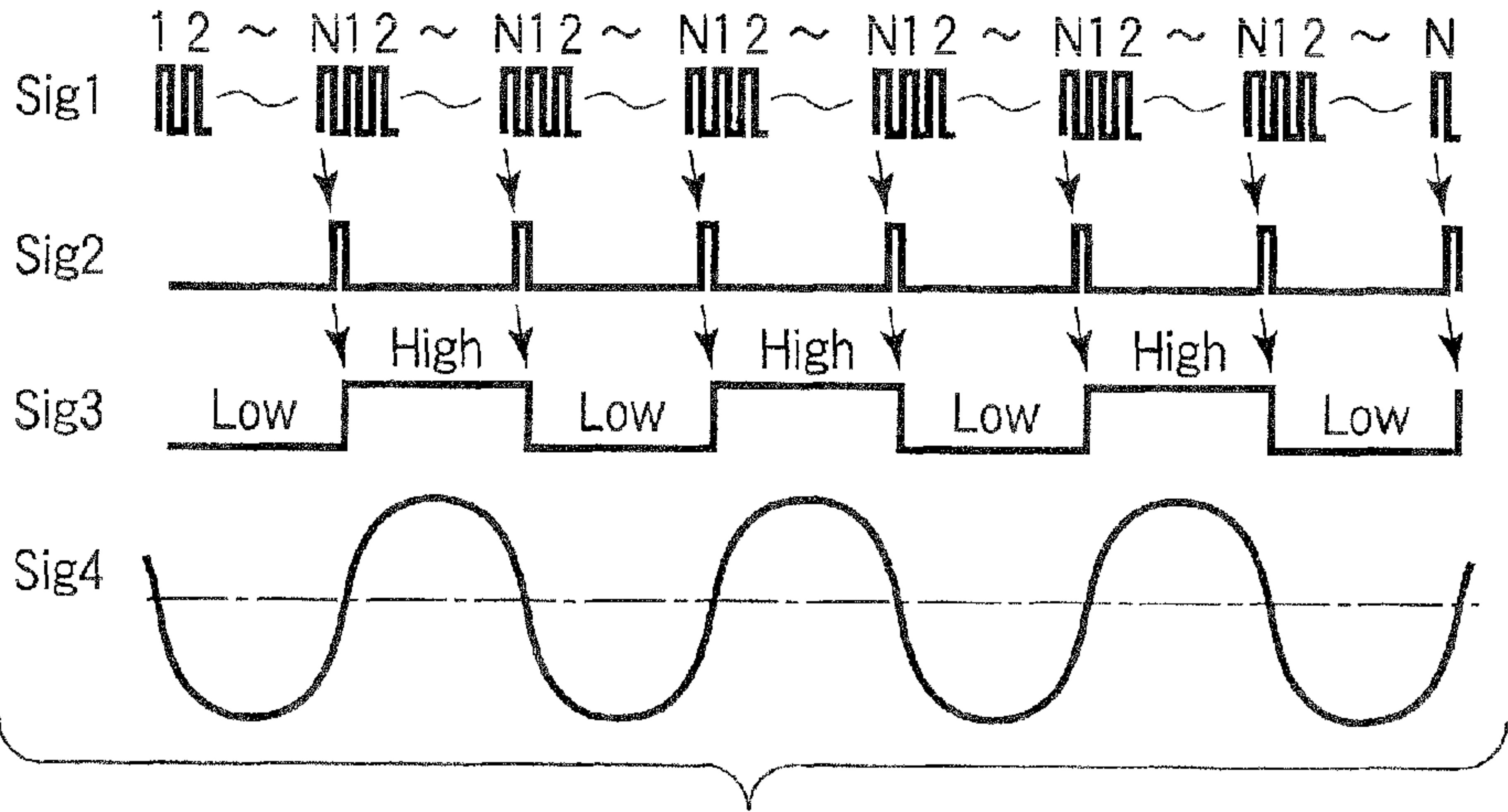
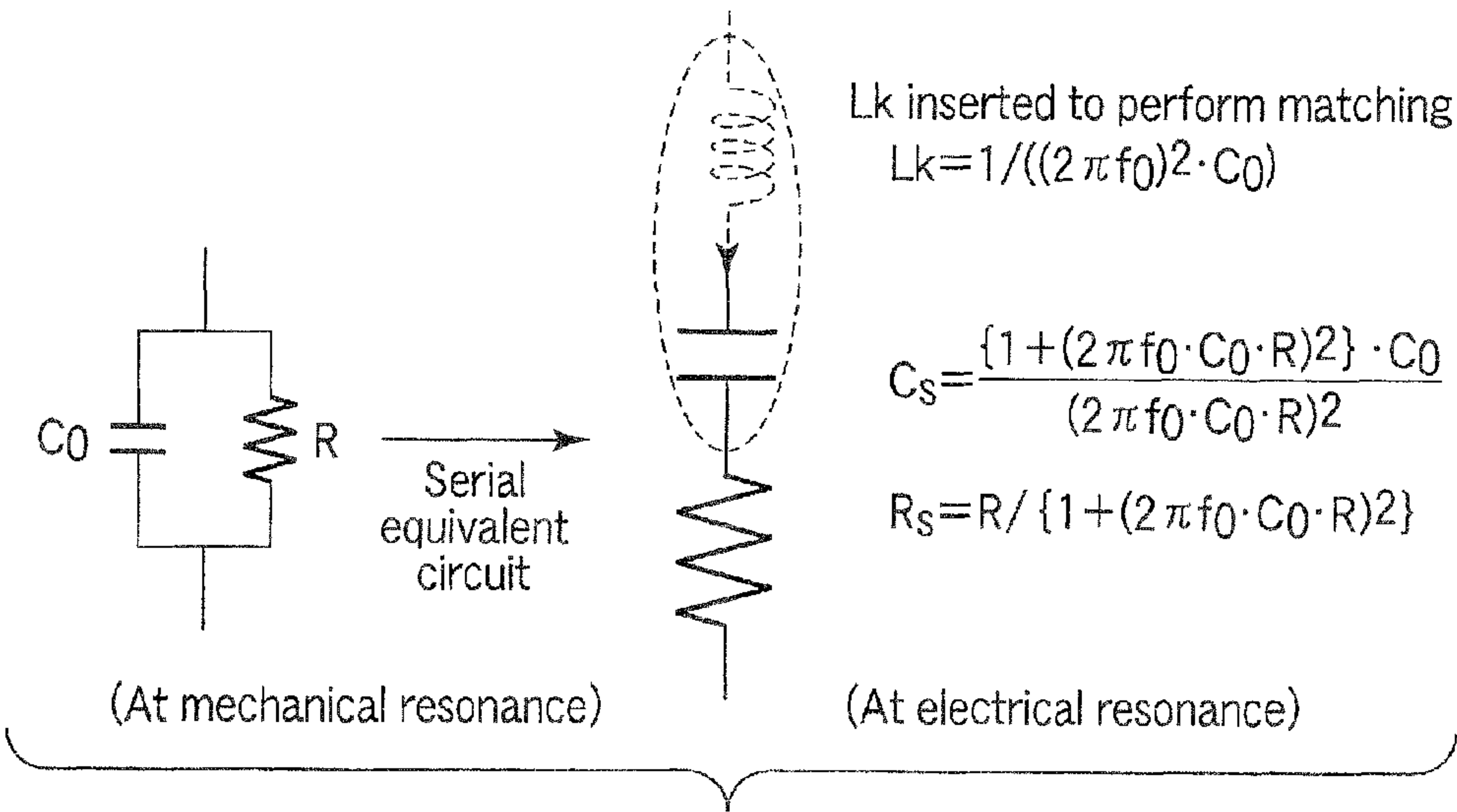
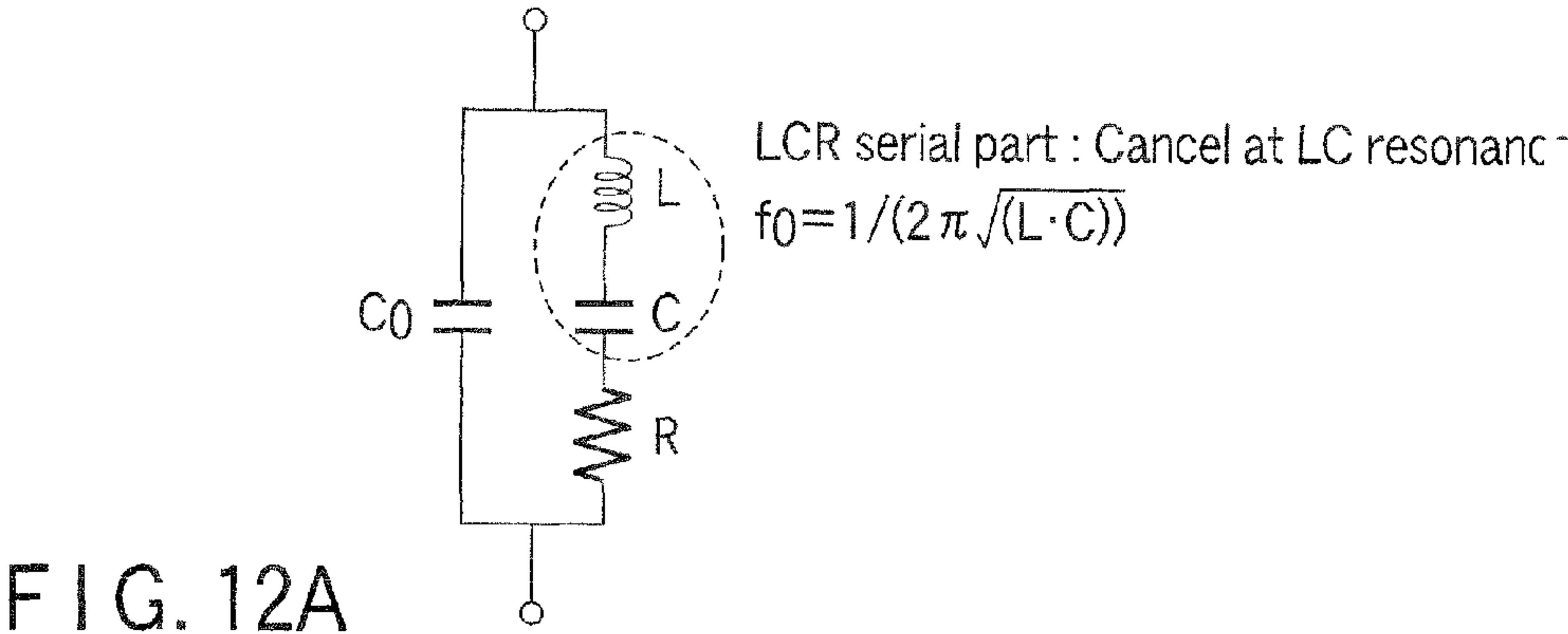


FIG. 10







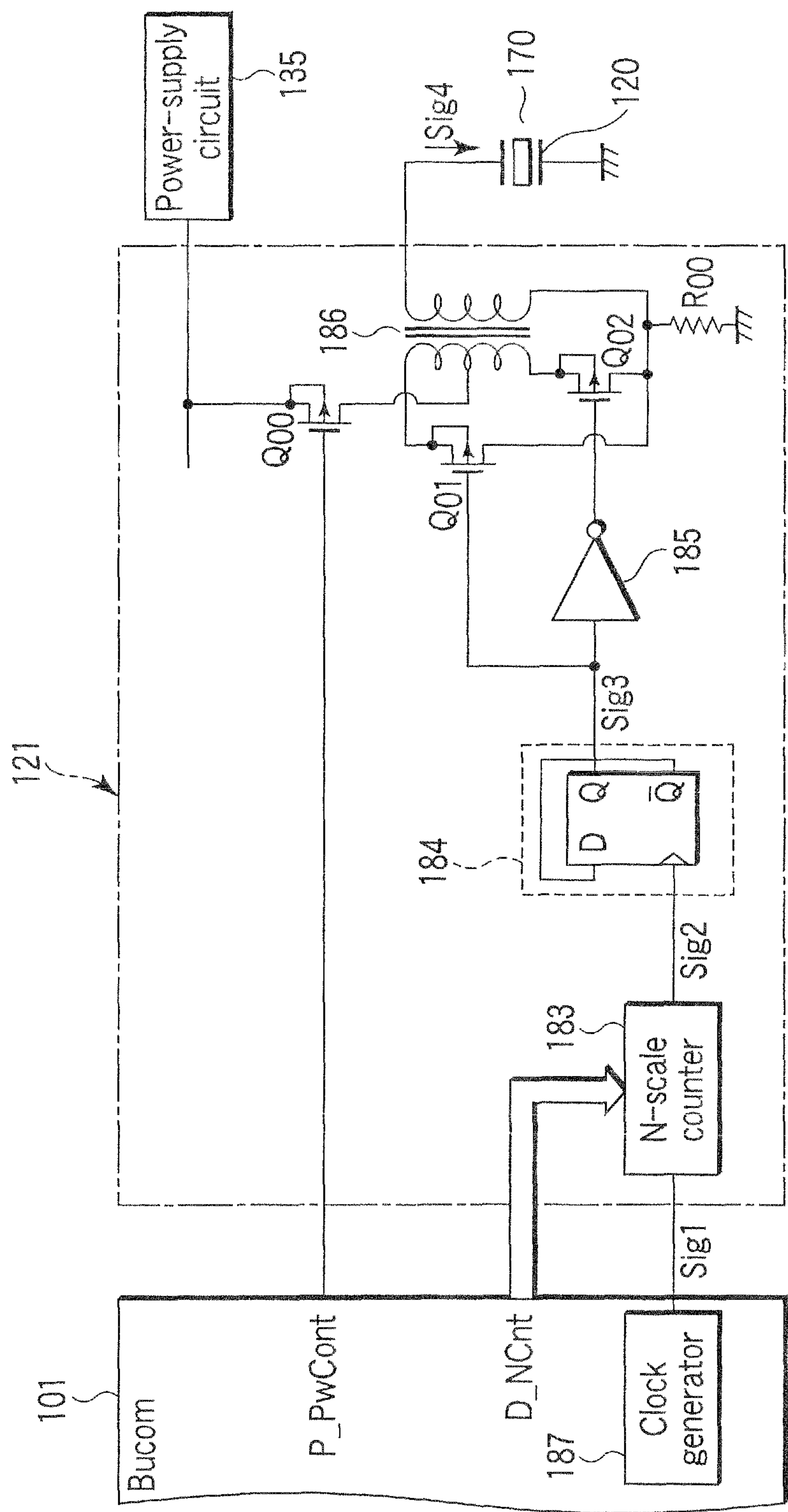


FIG. 13



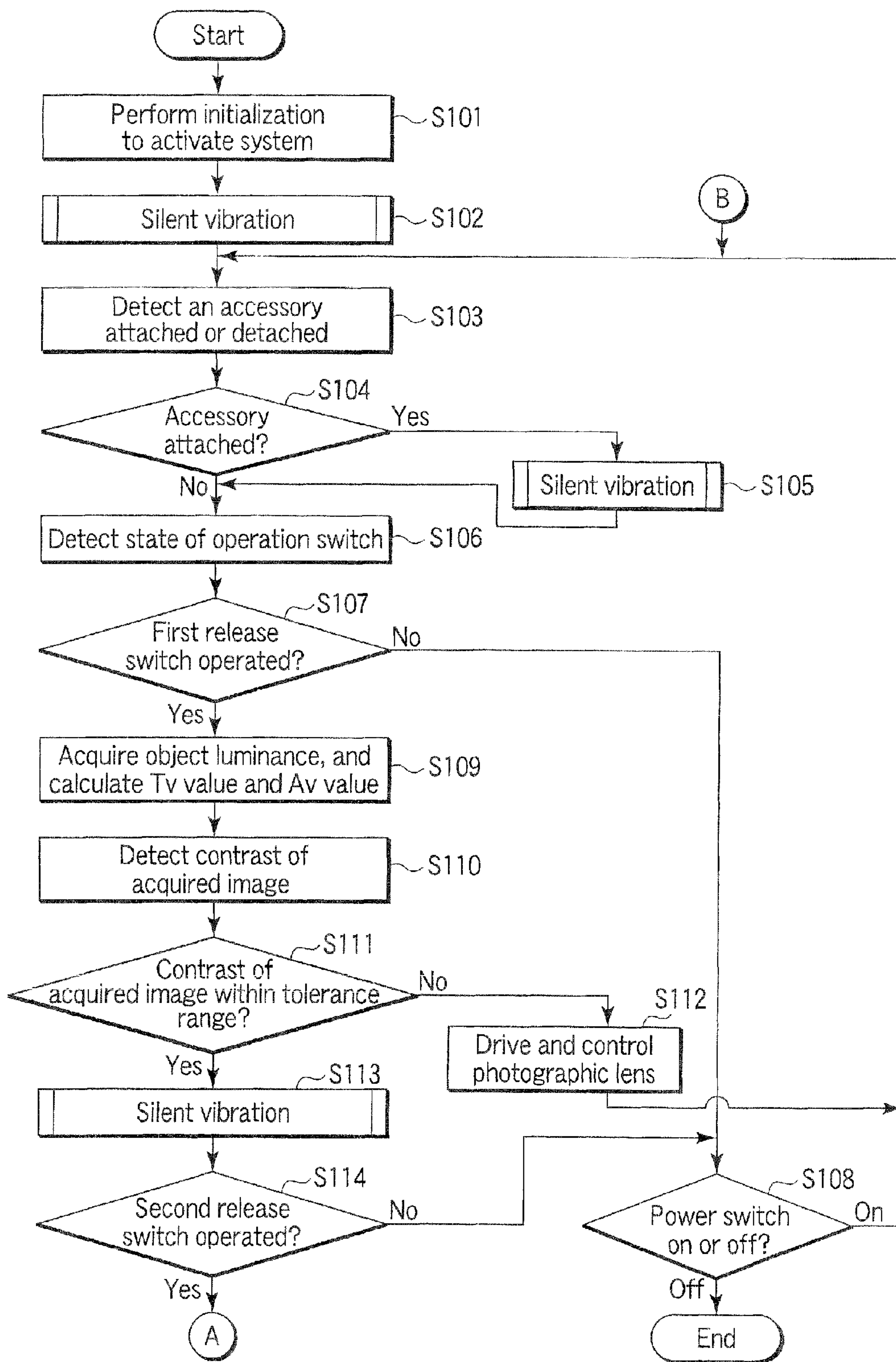


FIG. 15A

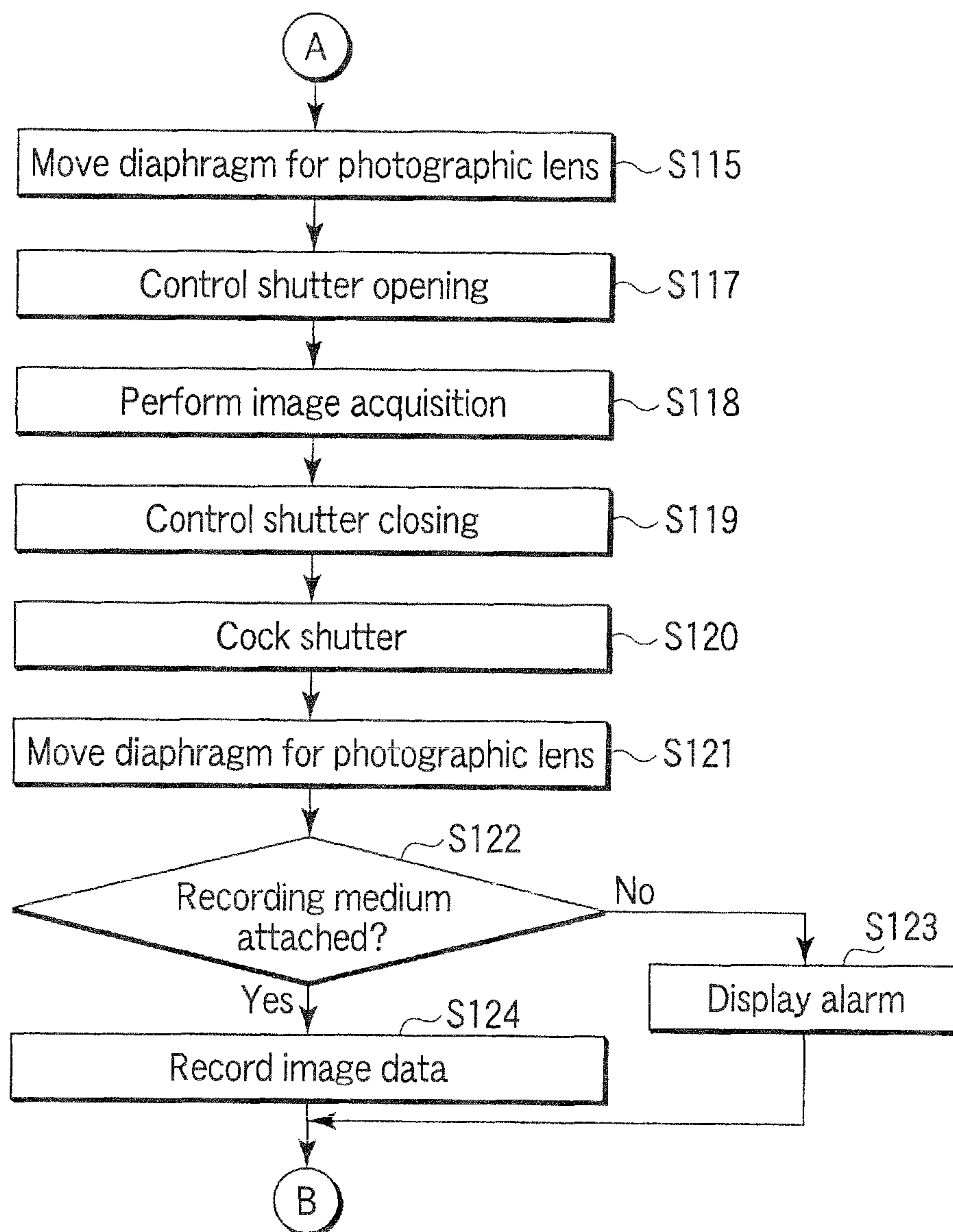


FIG. 15B



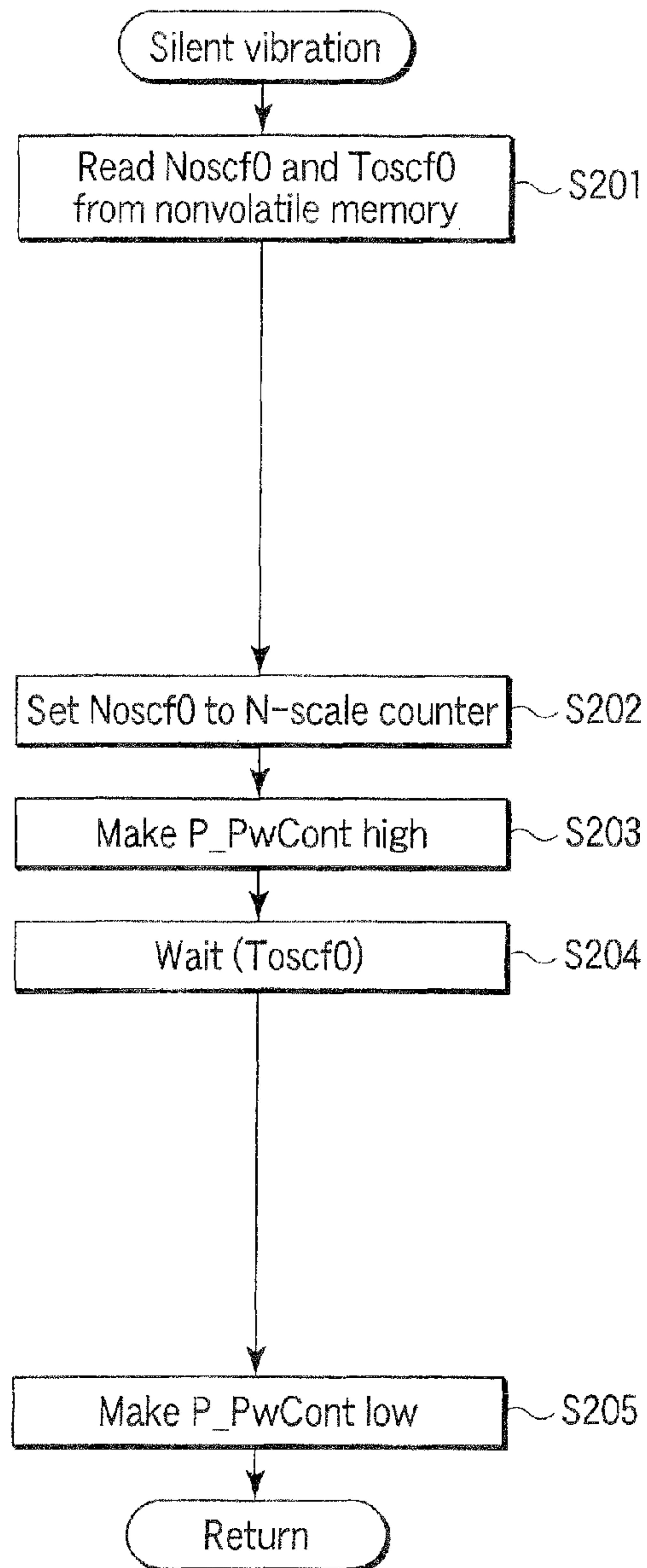


FIG. 16

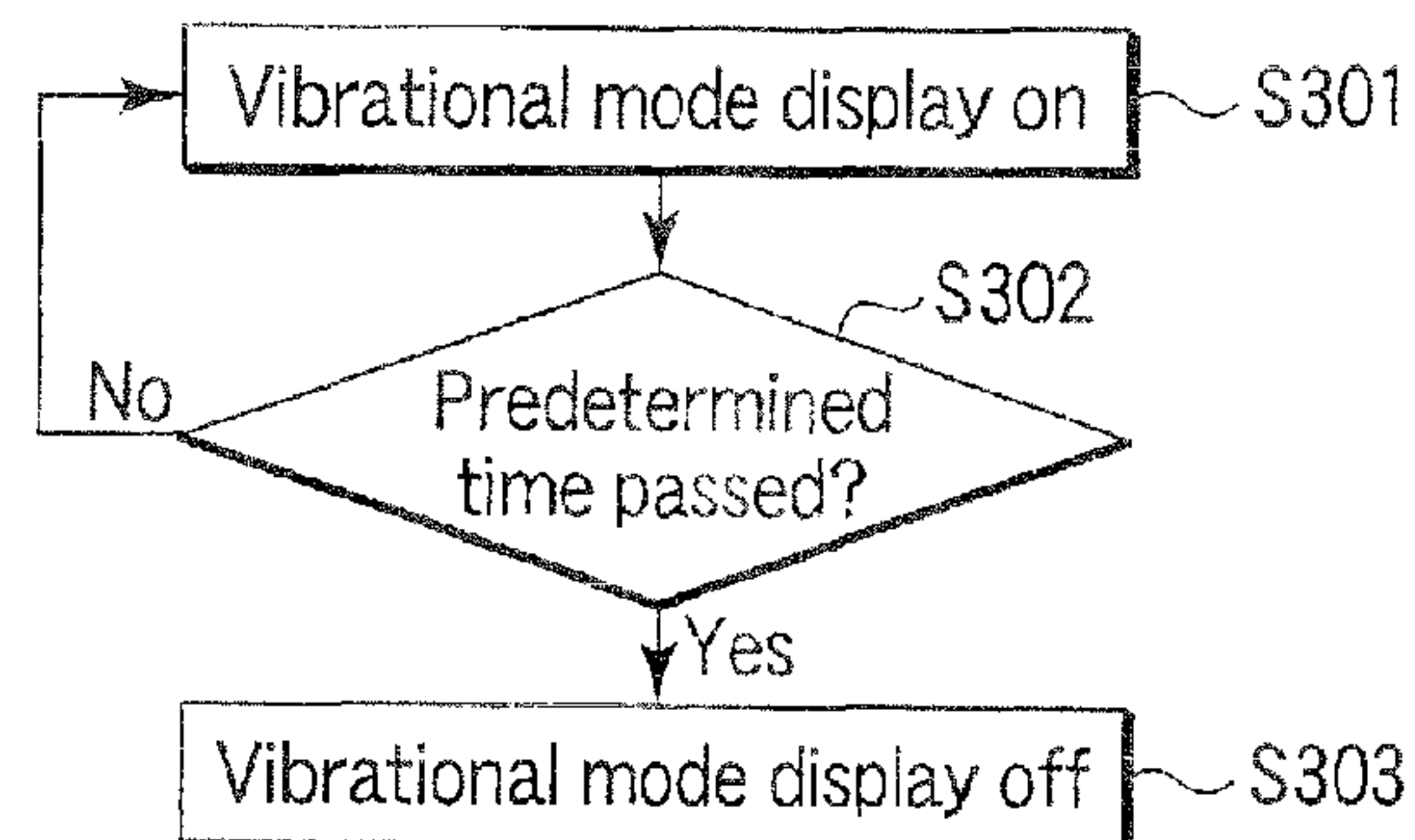


FIG. 17

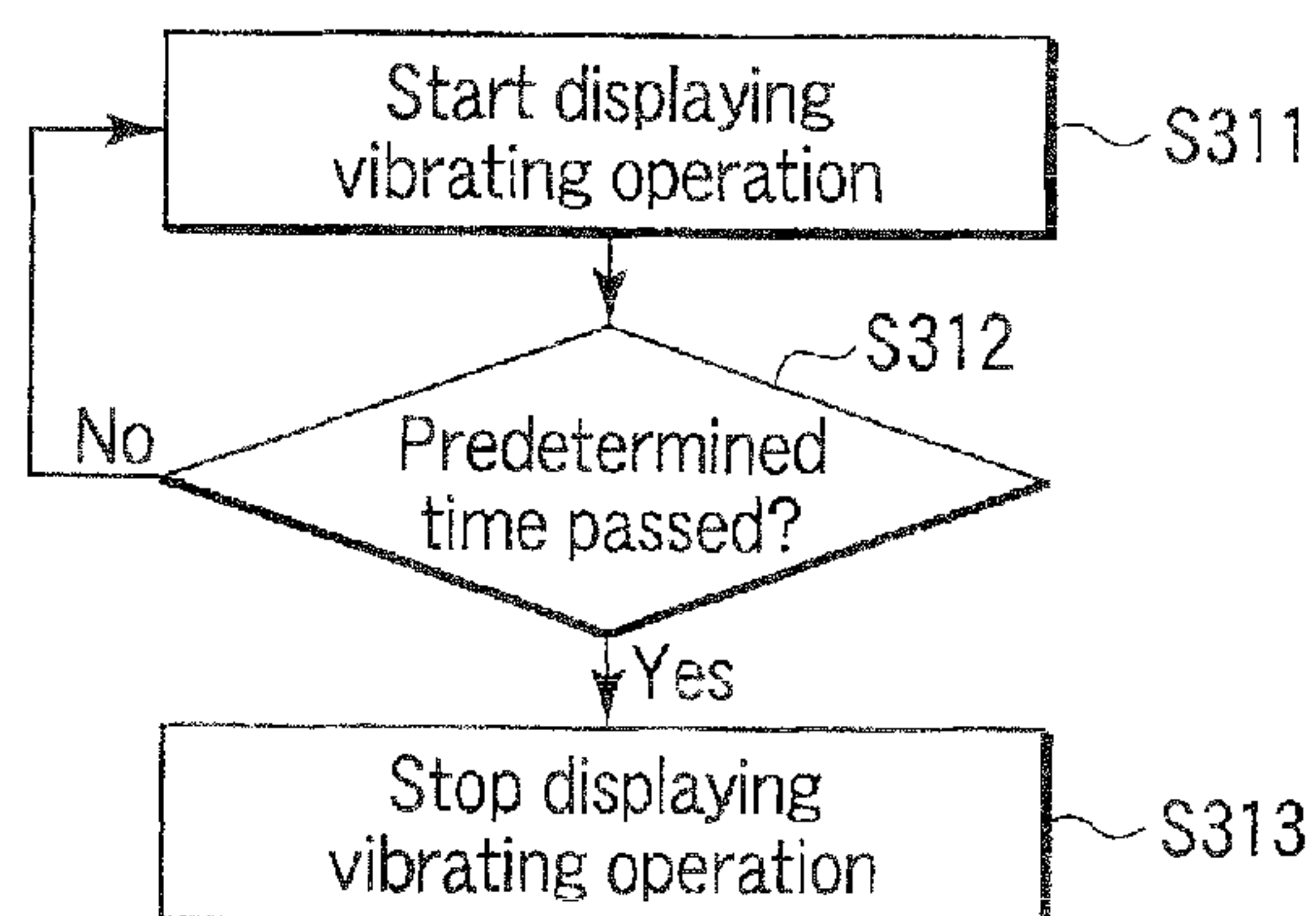


FIG. 18

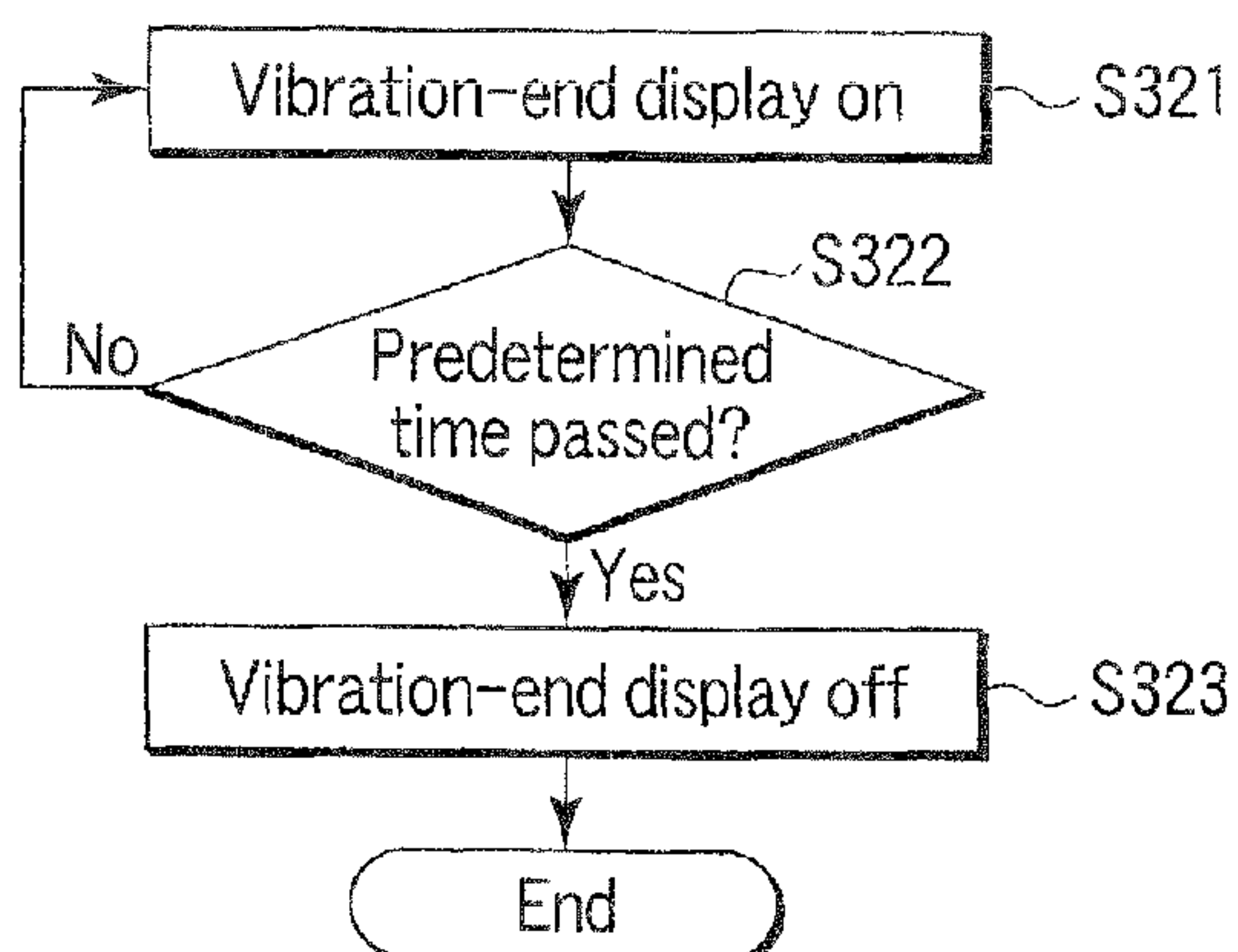


FIG. 19

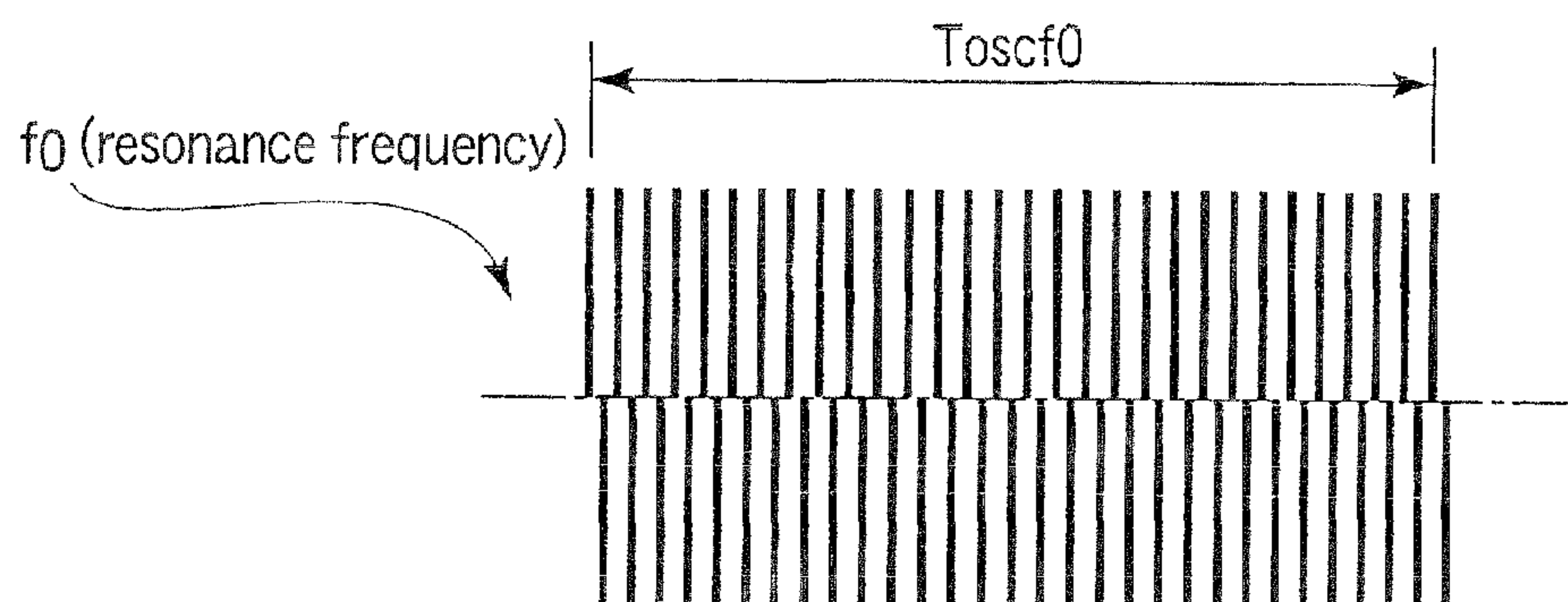


FIG. 20

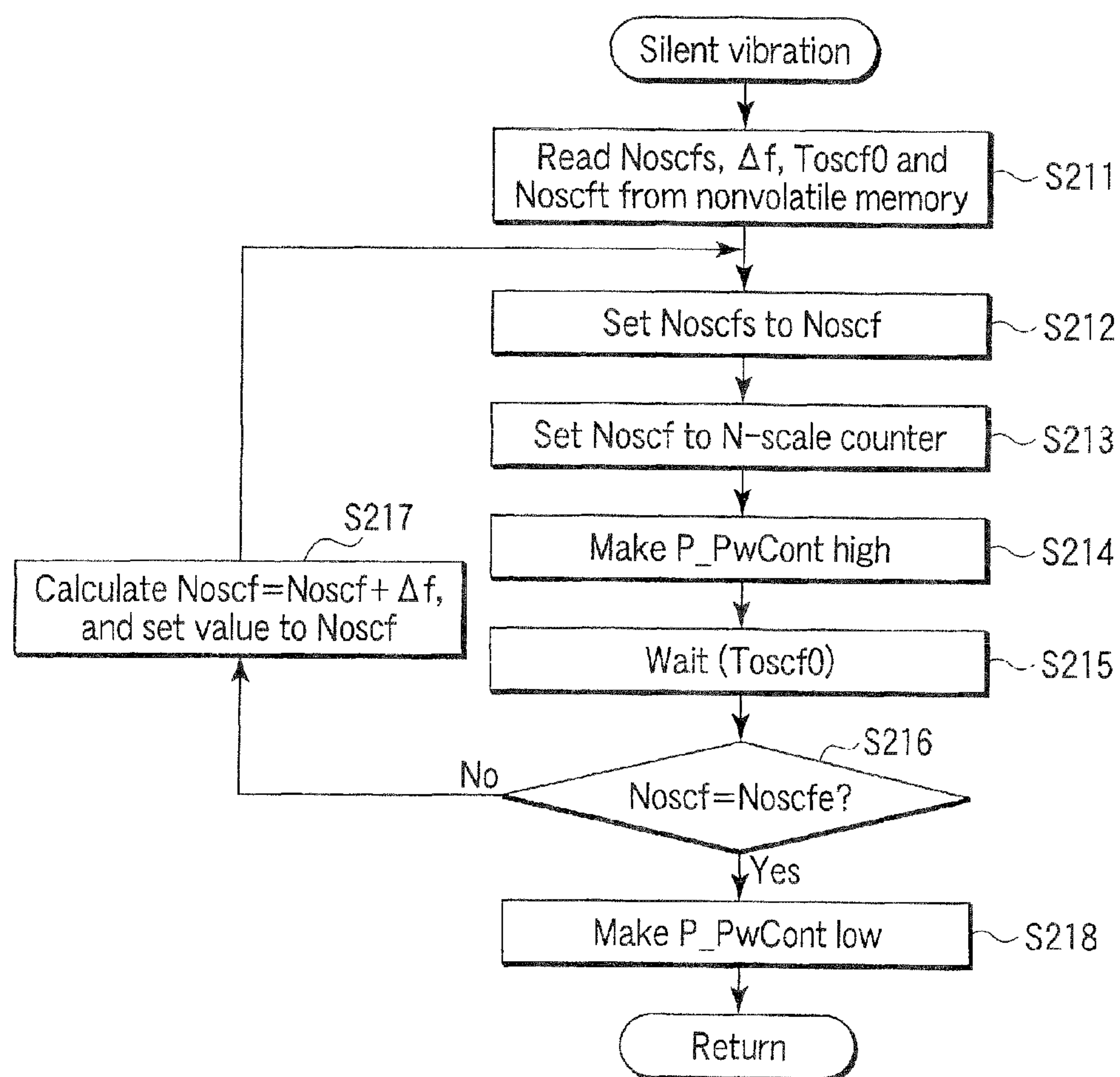


FIG. 21

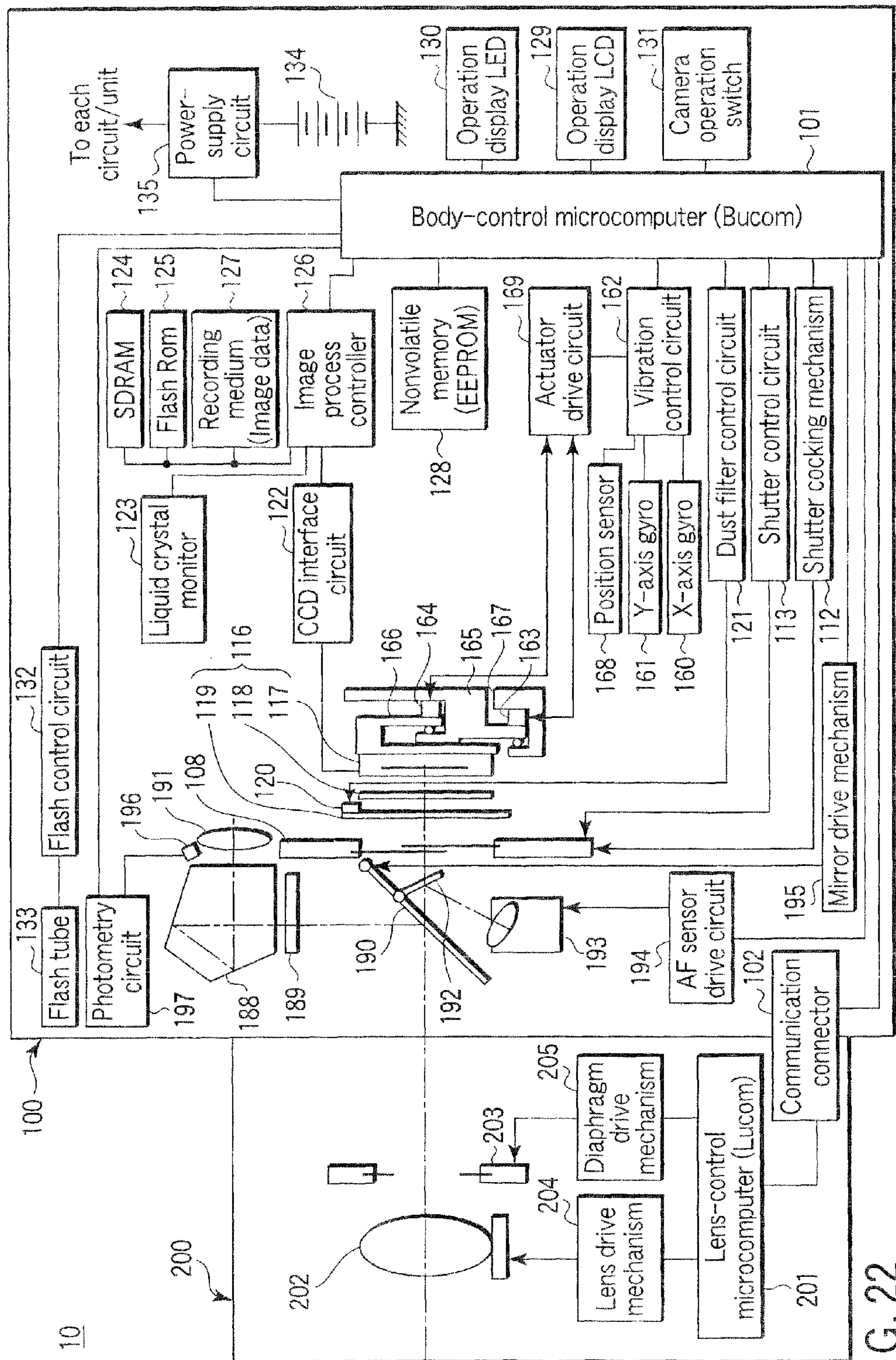


FIG. 22



# VIBRATING DEVICE AND IMAGE EQUIPMENT HAVING THE SAME

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2010-101495, filed Apr. 26, 2010, the entire contents of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to image equipment having image forming elements such as an image sensor element or a display element, and also to a vibrating device designed to vibrate the dust-screening member that is arranged at the front of each image forming element of such an image equipment.

### 2. Description of the Related Art

As image equipment having image forming elements, there is known an image acquisition apparatus that has an image sensor element configured to produce a video signal corresponding to the light applied to its photoelectric conversion surface. Also known is an image projector that has a display element, such as liquid crystal element, which displays an image on a screen. In recent years, image equipment having such image forming elements have been remarkably improved in terms of image quality. If dust adheres to the surface of the image forming element such as the image sensor element or display element or to the surface of the transparent member (optical element) that is positioned in front of the image forming element, the image produced will have shadows of the dust particles. This makes a great problem.

For example, digital cameras of called "lens-exchangeable type" have been put to practical use, each comprising a camera body and a photographic optical system removably attached to the camera body. The lens-exchangeable digital camera is so designed that the user can use various kinds of photographic optical systems, by removing the photographic optical system from the camera body and then attaching any other desirable photographic optical system to the camera body. When the photographic optical system is removed from the camera body, the dust floating in the environment of the camera flows into the camera body, possibly adhering to the surface of the image sensor element or to the surface of the transparent member (optical element), such as a lens, cover glass or the like, that is positioned in front of the image sensor element. The camera body contains various mechanisms, such as a shutter and a diaphragm mechanism. As these mechanisms operate, they produce dust, which may adhere to the surface of the image sensor element as well.

Projectors have been put to practical use, too, each configured to enlarge an image displayed by a display element (e.g., CRT or liquid crystal element) and project the image onto a screen so that the enlarged image may be viewed. In such a projector, too, dust may adhere to the surface of the display element or to the surface of the transparent member (optical element), such as a lens, cover glass or the like, that is positioned in front of the display element, and enlarged shadows of the dust particles may inevitably be projected to the screen.

Various types of mechanisms that remove dust from the surface of the image forming element or the transparent mem-

ber (optical element) that is positioned in front of the image sensor element, provided in such image equipment have been developed.

In an electronic image acquisition apparatus disclosed in, for example, U.S. 2004/0169761 A1, a ring-shaped piezoelectric element (vibrating member) is secured to the circumferential edge of a glass plat shaped like a disc (dust-screening member). When a voltage of a prescribed frequency is applied to the piezoelectric element, the glass plat shaped like a disc undergoes a standing-wave, bending vibration having nodes at the concentric circles around the center of the glass plat shaped like a disc. This vibration removes the dust from the glass disc. The vibration (vibrational mode 1) produced by the voltage of the prescribed frequency is a standing wave having nodes at the concentric circles around the center of the disc. The dust particles at these nodes cannot be removed, because the amplitude of vibration at the nodes is small. In view of this, the glass plat shaped like a disc is vibrated at a different frequency, achieving a standing-wave vibration (vibrational mode 2) that has nodes at concentric circles different from those at which the nodes of vibrational mode 1 are located. Thus, those parts of the glass disc, where the nodes lie in vibrational mode 1, are vibrated at large amplitude.

Jpn. Pat. Appln. KOKAI Publication No. 2007-228246 discloses a rectangular dust-screening member and piezoelectric elements secured to the opposite sides of the dust-screening member, respectively. The piezoelectric elements produce vibration at a predetermined frequency, resonating the dust-screening member. Vibration is thereby achieved in such mode that nodes extend parallel to the sides of the dust-screening member. Further, as in the mechanism of U.S. 2004/0169761 A1, the dust-screening member is made to resonate at a different frequency, accomplishing a standing-wave vibrational mode, in order to change the opposition of nodes. Any one of these vibrational modes achieves bending vibration having nodes extending parallel to the sides of the dust-screening member.

## BRIEF SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a vibrating device comprising:

a dust-screening member which is shaped like a plate as a whole, and has at least one side that is symmetric with respect to a virtual axis on a surface of the plate-like member;

a vibrating member adjacent to one side of the dust screening member and arranged on the surface along the one side, and configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to the surface of the dust-screening member; and

a drive unit configured to drive the vibrating member to produce the vibration, such that peak ridges of the vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member form a closed loop, and an area including a center of the closed loop is surrounded by a node area having almost no vibrational amplitude perpendicular to the surface of the dust-screening member, on the surface of the dust-screening member.

According to a second aspect of the present invention, there is provided an image equipment comprising:

an image forming element having an image surface on which an optical image is formed;

a dust-screening member which is shaped like a plate as a whole, has at least one side that is symmetric with respect to a virtual axis on a surface of the plate-like member, and has a transparent area spread to a certain width, facing the image surface and spaced therefrom by a predetermined distance;



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a vibrating member adjacent to one side of the dust-screening member and arranged on the surface along the one side, and configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to a surface of the dust-screening member;

a drive unit configured to drive the vibrating member; and  
a sealing structure configured to seal an area formed between the image forming element and dust-screening member opposing to each other, at the circumferential edges of the image forming element and dust-screening member,

wherein the drive unit drives the vibrating member to produce the vibration, such that peak ridges of the vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member form a closed loop, and an area including a center of the closed loop is surrounded by a node area having almost no vibrational amplitude perpendicular to the surface of the dust-screening member, on the surface of the dust-screening member outside of the sealing structure.

According to a third aspect of the present invention, there is provided a vibrating device comprising:

a dust-screening member which is shaped like a plate as a whole, and has at least one side that is symmetric with respect to a virtual axis on a surface of the plate-like member;

a vibrating member adjacent to one side of the dust-screening member and arranged on the surface along the one side, and configured to produce, at the surface, vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member; and

a drive unit configured to drive the vibrating member to produce the vibration, which includes a part of each of peak ridges of vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member, the peak ridges are continuously and substantially concentrically located from the one side of the dust-screening member toward the other side opposed to the one side, and a center of the continuous and substantially concentric peak ridges is located opposite to the other side across the one side of the dust-screening member, on the surface of the dust-screening member.

Advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a block diagram schematically showing an exemplary system configuration, mainly electrical, of a lens-exchangeable, single-lens electronic camera (digital camera) that is a first embodiment of the image equipment according to this invention;

FIG. 2A is a vertical side view of an image sensor element unit of the digital camera, which includes a dust removal mechanism (or a sectional view taken along line A-A shown in FIG. 2B);

FIG. 2B is a front view of the dust removal mechanism, as viewed from the lens side;

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FIG. 3 is an exploded perspective view showing a major component (vibrator) of the dust removal mechanism;

FIG. 4A is a front view of a dust filter, explaining how the dust filter is vibrated;

FIG. 4B is a sectional view of the dust filter, taken along line B-B shown in FIG. 4A;

FIG. 4C is a sectional view of the dust filter, taken along line C-C shown in FIG. 4A;

FIG. 5 is a diagram explaining the dimensions of the long side, short side, and thickness of a dust filter and piezoelectric element;

FIG. 6 is a diagram explaining the concept of vibrating the dust filter;

FIG. 7 is a diagram explaining how the dust filter is vibrated in another mode;

FIG. 8 is a diagram showing the relation between the aspect ratio of the dust filter shown in FIG. 4A and the vibration speed ratio of the central vibrating area of the dust filter;

FIG. 9 is a diagram showing another configuration the dust filter may have;

FIG. 10 is a diagram showing still another configuration the dust filter may have;

FIG. 11 is a conceptual diagram of the dust filter, explaining the standing wave that is produced in the dust filter;

FIG. 12A is a diagram showing an electric equivalent circuit that drives the vibrator at a frequency near the resonance frequency;

FIG. 12B is a diagram showing an electric equivalent circuit that drives the vibrator at the resonance frequency;

FIG. 13 is a circuit diagram schematically showing the configuration of a dust filter control circuit;

FIG. 14 is a timing chart showing the signals output from the components of the dust filter control circuit;

FIG. 15A is the first part of a flowchart showing an exemplary camera sequence (main routine) performed by the microcomputer for controlling the digital camera body according to the first embodiment;

FIG. 15B is the second part of the flowchart showing the exemplary camera sequence (main routine);

FIG. 16 is a flowchart showing the operating sequence of "silent vibration" that is a subroutine shown in FIG. 15A;

FIG. 17 is a flowchart showing the operation sequence of the "display process" performed at the same time Step S201 of "silent vibration," i.e. subroutine (FIG. 16), is performed;

FIG. 18 is a flowchart showing the operating sequence of the "display process" performed at the same time Step S203 of "silent vibration," i.e., or subroutine (FIG. 16), is performed;

FIG. 19 is a flowchart showing the operating sequence of the "display process" performed at the same time Step S205 of "silent vibration," i.e., subroutine (FIG. 16), is performed;

FIG. 20 is a diagram showing the form of a resonance-frequency wave continuously supplied to vibrating members during silent vibration;

FIG. 21 is a flowchart showing the operating sequence of "silent vibration," i.e., subroutine in the operating sequence of the digital camera that is a second embodiment of the image equipment according to the present invention; and

FIG. 22 is a block diagram schematically showing an exemplary system configuration, mainly electrical, of a digital camera that is a third embodiment of the image equipment according to this invention.

#### DETAILED DESCRIPTION OF THE INVENTION

Best modes of practicing this invention will be described with reference to the accompanying drawings.



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## First Embodiment

An image equipment according to this invention, which will be exemplified below in detail, has a dust removal mechanism for the image sensor element unit that performs photoelectric conversion to produce an image signal. Here, a technique of improving the dust removal function of, for example, an electronic camera (hereinafter called "camera") will be explained. The first embodiment will be described, particularly in connection with a lens-exchangeable single-lens electronic camera (digital camera), with reference to FIGS. 1 to 2B.

First, the system configuration of a digital camera 10 according to this embodiment will be described with reference to FIG. 1. The digital camera 10 has a system configuration that comprises body unit 100 used as camera body, and a lens unit 200 used as an exchange lens, i.e., one of accessory devices.

The lens unit 200 can be attached to and detached from the body unit 100 via a lens mount (not shown) provided on the front of the body unit 100. The control of the lens unit 200 is performed by the lens-control microcomputer (hereinafter called "Lucom") 201 provided in the lens unit 200. The control of the body unit 100 is performed by the body-control microcomputer (hereinafter called "Bucom") 101 provided in the body unit 100. By a communication connector 102, the Lucom 201 and the Bucom 101 are electrically connected to each other, communicating with each other, while the lens unit 200 remains attached to the body unit 100. The Lucom 201 is configured to cooperate, as subordinate unit, with the Bucom 101.

The lens unit 200 further has a photographic lens 202, a diaphragm 203, a lens drive mechanism 204, and a diaphragm drive mechanism 205. The photographic lens 202 is driven by a stepping motor (not shown) that is provided in the lens drive mechanism 204. The diaphragm 203 is driven by a stepping motor (not shown) that is provided in the diaphragm drive mechanism 205. The Lucom 201 controls these motors in accordance with the instructions made by the Bucom 101.

In the body unit 100, a shutter 108, a shutter cocking mechanism 112, and a shutter control circuit 113 are arranged as shown in FIG. 1. The shutter 108 is a focal plane shutter arranged on the photographic optical axis. The shutter cocking mechanism 112 biases the spring (not shown) that drives the front curtain and rear curtain of the shutter 108. The shutter control circuit 113 controls the motions of the front curtain and rear curtain of the shutter 108.

In the body unit 100, an image acquisition unit 116 is further provided to perform photoelectric conversion on the image of an object, which has passed through the above-mentioned optical system. The image acquisition unit 116 is a unit composed of a CCD 117 that is an image sensor element as an image forming element, an optical low-pass filter (LPE) 118 that is arranged in front of the CCD 117, and a dust filter 119 that is a dust-screening member. Thus, in this embodiment, a transparent glass plate (optical element) that has, at least at its transparent part, a refractive index different from that of air is used as the dust filter 119. Nonetheless, the dust filter 119 is not limited to a glass plate (optical element). Any other member (optical element) that exists in the optical path and can transmit light may be used instead. For example, the transparent glass plate (optical element) may be replaced by an optical low-pass filter (LPF), an infrared-beam filter, a deflection filter, a half mirror, or the like. In this case, the frequency and drive time pertaining to vibration and the position of a vibration member (later described) are set in accordance with the member (optical element). The CCD 117 is

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used as an image sensor element. Nonetheless, any other image sensor element, such as CMOS or the like, may be used instead.

As mentioned above, the dust filter 119 can be selected from various devices including an optical low-pass filter (LPF). However, this embodiment will be described on the assumption that the dust filter is a glass plate (optical element).

On one side of the circumferential edge of the dust filter 119, a piezoelectric element 120 is attached. The piezoelectric element 120 has two electrodes. A dust filter control circuit 121, which is a drive unit, drives the piezoelectric element 120 at the frequency determined by the size and material of the dust filter 119. As the piezoelectric element 120 vibrates, the dust filter 119 undergoes specific vibration. Dust can thereby be removed from the surface of the dust filter 119. To the image acquisition unit 116, an anti-vibration unit is attached to compensate for the motion of the hand holding the digital camera 10.

The digital camera 10 according to this embodiment further has a COD interface circuit 122, a liquid crystal monitor 123, an SDRAM 124, a Flash ROM 125, and an image process controller 126, thereby to perform not only an electronic image acquisition function, but also an electronic record/display function. The electronic image acquisition function includes a so-called through image display function, which displays an image acquired by the CCD 117 as a moving image on the liquid crystal monitor 123, and uses it as a viewfinder, and a moving image recording function which records a moving image. As a viewfinder function, an optical single-lens reflex viewfinder or the like may be provided. The CCD interface circuit 122 is connected to the CCD 117. The SDRAM 124 and the Flash ROM 125 function as storage areas. The image process controller 126 uses the SDRAM 124 and the Flash ROM 125, to process image data. A recording medium 127 is removably connected by a communication connector (not shown) to the body unit 100 and can therefore communicate with the body unit 100. The recording medium 127 is an external recording medium, such as one of various memory cards or an external HDD, and records the image data acquired by photography. As another storage area, a nonvolatile memory 128, e.g., EEPROM, is provided and can be accessed from the Bucom 101. The nonvolatile memory 128 stores prescribed control parameters that are necessary for the camera control.

To the Bucom 101, there are connected an operation display LCD 129, an operation display LED 130, a camera operation switch 131, and a flash control circuit 132. The operation display LCD 129 and the operation display LED 130 display the operation state of the digital camera 10, informing the user of this operation state. The operation display LED 129 or the operation display LED 130 has, for example, a display unit configured to display the vibration state of the dust filter 119 as long as the dust filter control circuit 121 keeps operating. The camera operation switch 131 is a group of switches including, for example, a release switch, a mode changing switch, a power switch, which are necessary for the user to operate the digital camera 10. The flash control circuit 132 drives a flash tube 133.

In the body unit 100, a battery 134 used as power supply and a power-supply circuit 135 are further provided. The power-supply circuit 135 converts the voltage of the battery 134 to a voltage required in each circuit unit of the digital camera 10 and supplies the converted voltage to the each circuit unit. In the body unit 100, too, a voltage detecting circuit (not shown) is provided, which detects a voltage



change at the time when a current is supplied from an external power supply through a jack (not shown).

The components of the digital camera **10** configured as described above operate as will be explained below. The image process controller **126** controls the CCD interface circuit **122** in accordance with the instructions coming from the Bucom **101**, whereby image data is acquired from the CCD **117**. The image data is converted to a video signal by the image process controller **126**. The image represented by the video signal is displayed by the liquid crystal monitor **123**. Viewing the image displayed on the liquid crystal monitor **123**, the user can confirm the image photographed.

The SDRAM **124** is a memory for temporarily store the image data and is used as a work area in the process of converting the image data. The image data is held in the recording medium **127**, for example, after it has been converted to JPEG data. Here, when image data is for a moving image, it is converted into MPEG data.

The photographic lens **202** is focused as follows. Images are acquired by sequentially changing the position of the photographic lens **202**. Among the acquired images, a position with the highest contrast is calculated by the Bucom **101**. This position is transmitted from the Bucom **101** to the Lucom **201** through the communication connector **102**. The Lucom **201** controls the photographic lens **202** to this position. As for photometric measurement, know measurement is performed based on the amount of light detected from an acquired image.

The image acquisition unit **116** that includes the CCD **117** will be described with reference to FIGS. 2A and 2B. Note that the hatched parts shown in FIG. 2B show the shapes of members clearly, not to illustrating the sections thereof.

As described above, the image acquisition unit **116** has the CCD **117**, the optical LPF **118**, the dust filter **119**, and the piezoelectric element **120**. The CCD **117** is an image sensor element that produces an image signal that corresponds to the light applied to its photoelectric conversion surface through the photographic optical system. The optical LPF **118** is arranged at the photoelectric conversion surface of the CCD **117** and removes high-frequency components from the light beam coming from the object through the photographic optical system. The dust filter **119** is a dust-screening member arranged in front of the optical LPF **118** and facing the optical LPF **118**, spaced apart therefrom by a predetermined distance. The piezoelectric element **120** is arranged on the circumferential edge of the dust filter **119** and is vibrating members for applying specific vibration to the dust filter **119**.

The CCD chip **136** of the CCD **117** is mounted directly on a flexible substrate **137** that is arranged on a fixed plate **138**. From the ends of the flexible substrate **137**, connection parts **139a** and **139b** extend. Connectors **140a** and **140b** are provided on a main circuit board **141**. The connection parts **139a** and **139b** are connected to the connectors **140a** and **140b**, whereby the flexible substrate **137** is connected to the main circuit board **141**. The CCD **117** has a protection glass plate **142**. The protection glass plate **142** is secured to the flexible substrate **137**, with a spacer **143** interposed between it and the flexible substrate **137**.

Between the CCD **117** and the optical LPF **118**, a filter holding member **144** made of elastic material is arranged on the front circumferential edge of the CCD **117**, at a position where it does not cover the effective area of the photoelectric conversion surface of the CCD **117**. The filter holding member **144** abuts on the optical LPF **118**, at a part close to the rear circumferential edge of the optical LPF **118**. The filter holding member **144** functions as a sealing member that maintains the junction between the CCD **117** and the optical LPF **118**

almost airtight. A holder **145** is provided, covering seals the COD **117** and the optical LPF **118** in airtight fashion. The holder **145** has a rectangular opening **146** in a part that is substantially central around the photographic optical axis. The inner circumferential edge of the opening **146**, which faces the dust filter **119**, has a stepped part **147** having an L-shaped cross section. Into the opening **146**, the optical LPF **118** and the CCD **117** are fitted from the back. In this case, the front circumferential edge of the optical LPF **118** contacts the stepped part **147** in a virtually airtight fashion. Thus, the optical LPF **118** is held by the stepped part **147** at a specific position in the direction of the photographic optical axis. The optical LPF **118** is therefore prevented from slipping forwards from the holder **145**. The level of airtight sealing between the CCD **117** and the optical LPF **118** is sufficient to prevent dust from entering to form an image having shadows of dust particles. In other words, the sealing level need not be so high as to completely prevent the in-flow of gasses.

On the front circumferential edge of the holder **145**, a dust-filter holding unit **148** is provided, covering the entire front circumferential edge of the holder **145**. The dust-filter holding unit **148** is formed, surrounding the stepped part **147** and projecting forwards from the stepped part **147**, in order to hold the dust filter **119** in front of the LPF **118** and to space the filter **119** from the stepped part **147** by a predetermined distance. The opening of the dust-filter holding unit **148** serves as focusing-beam passing area **149**. The dust filter **119** is shaped like a polygonal plate as a whole (a square plate, in this embodiment). The dust filter **119** is supported on the dust-filter holding unit **148**, pushed onto the dust-filter holding unit **148** by a pushing member **150** which is constituted by an elastic body such as a leaf spring and has one end fastened with screws **151** to the dust-filter holding unit **148**. More specifically, a cushion member **152** made of vibration attenuating material, such as rubber or resin, is interposed between the pushing member **150** and the dust filter **119**. On the other hand, between the back of the dust filter **119** and the dust-filter holding unit **148**, a seal **156** made of vibration-damping material such as rubber is inserted. The cushion members **152** and seal **156** press and support the dust filter **119** to prevent the vibration of the dust filter **119** from being transmitted to the pushing member **150** and holder **145**. Cushion members **153** are provided in the dust filter holding unit **148** at the position corresponding to the cushion member **152**. The cushion members **153** receive the dust filter **119**, when an external force is applied to the dust filter **119**, and the dust filter **119** is displaced. The dust filter **119** is positioned with respect to the Y-direction in the plane that is perpendicular to the optical axis, as that part of the pushing member **150** which is bent in the Z-direction, receive a force through a support member **154**. On the other hand, the dust filter **119** is positioned with respect to the X-direction in the plane that is perpendicular to the optical axis, as a support part **155** provided on the holder **145** receive a force through the support member **154**, as is illustrated in FIG. 2B. The support member **154** is made of vibration-attenuating material such as rubber or resin, too, not to impede the vibration of the dust filter **119**. The cushion members **152** and **153** may be located at nodes of the vibration of the dust filter **119**, which will be described later. In this case, the vibration of the dust filter **119** will be almost impeded. This can provide an efficient dust removal mechanism that achieves vibration of large amplitude. Between the circumferential edge of the dust filter **119** and the dust-filter holding unit **148**, the seal **156** having an annular lip part is arranged, supporting the dust filter **119** and defining an airtight space including an opening **146**. The annular lip part supports the dust filter **119** at the position which becomes a



node of the vibration generated in the dust filter 119 as described later. In this configuration, an efficient dust removal mechanism with a large vibrational amplitude is realized without substantially interrupting the vibration of the dust filter 119. The cushion members 152 and 153 and the holder 145 formed in a desired size to mount the CCD 117 as an image forming element constitute a sealing structure to seal at the circumferential edges of the CCD 117 and dust filter 119. The image acquisition unit 116 is configured, so that the area formed by the opposing CCD 117 and dust filter 119 is airtight by the above sealing structure. The level of airtight sealing between the dust filter 119 and the dust-filter holding unit 148 is sufficient to prevent dust from entering to form an image having shadows of dust particles. The sealing level need not be so high as to completely prevent the in-flow of gasses.

To the end of the piezoelectric element 120, which is vibrating member, flex 157, i.e., flexible printed board, is electrically connected. The flex 157 inputs an electric signal (later described) from the dust filter control circuit 121 to the piezoelectric element 120, causing the element 120 to vibrate in a specific way. The flex 157 is made of resin and copper etc., and has flexibility. Therefore, the flex 157 little attenuates the vibration of the piezoelectric element 120. The flex 157 is provided at position where the vibrational amplitude is small (at the nodes of vibration, which will be described later), and can therefore suppress the attenuation of vibration. The piezoelectric element 120 moves relative to the body unit 100 if the camera 10 has such a hand-motion compensating mechanism as will be later described. Hence, if the dust filter control circuit 121 is held by a holding member formed integral with the body unit 100, the flex 157 is deformed and displaced as the hand-motion compensating mechanism operates. In this case, the flex 157 effectively works because it is thin and flexible. In the present embodiment, the flex 157 has a simple configuration, extending from one position. It is best fit for use in cameras having a hand-motion compensating mechanism.

The dust removed from the surface of the dust filter 119 falls onto the bottom of the body unit 100, by virtue of the vibration inertia and the gravity. In this embodiment, a base 158 is arranged right below the dust filter 119, and a holding member 159 made of, for example, adhesive tape, is provided on the base 158. The holding member 159 reliably traps the dust fallen from the dust filter 119, preventing the dust from moving back to the surface of the dust filter 119.

The hand-motion compensating mechanism will be explained in brief. As shown in FIG. 1, the hand-motion compensating mechanism is composed of an X-axis gyro 160, a Y-axis gyro 161, a vibration control circuit 162, an X-axis actuator 163, a Y-axis actuator 164, an X-frame 165, a Y-frame 166 (holder 145), a frame 167, a position sensor 168, and an actuator drive circuit 169. The X-axis gyro 160 detects the angular velocity of the camera when the camera moves, rotating around the X axis. The Y-axis gyro 161 detects the angular velocity of the camera when the camera rotates around the Y axis. The vibration control circuit 162 calculates a value by which to compensate the hand motion, from the angular-velocity signals output from the X-axis gyro 160 and Y-axis gyro 161. In accordance with the hand-motion compensating value thus calculated, the actuator drive circuit 169 moves the CCD 117 in the X-axis direction and Y-axis direction, which are first and second directions orthogonal to each other in the XY plane that is perpendicular to the photographic optical axis, thereby to compensate the hand motion, if the photographic optical axis is taken as Z axis. More precisely, the X-axis actuator 163 drives the X-frame 165 in

the X-axis direction upon receiving a drive signal from the actuator drive circuit 169, and the Y-axis actuator 164 drives the Y-frame 166 in the Y-axis direction upon receiving a drive signal from the actuator drive circuit 169. That is, the X-axis actuator 163 and the Y-axis actuator 164 are used as drive sources, the X-frame 165 and the Y-frame 166 (holder 145) which holds the CCD 117 of the image acquisition unit 116 are used as objects that are moved with respect to the frame 167. Note that the X-axis actuator 163 and the Y-axis actuator 164 are each composed of an electromagnetic motor, a feed screw mechanism, and the like. Alternatively, each actuator may be a linear motor using a voice coil motor, a linear piezoelectric motor or the like. The position sensor 168 detects the position of the X-frame 165 and the position of the Y-frame 166. On the basis of the positions the position sensor 168 have detected, the vibration control circuit 162 controls the actuator drive circuit 169, which drives the X-axis actuator 163 and the Y-axis actuator 164. The position of the CCD 117 is thereby controlled.

The dust removal mechanism of the first embodiment will be described in detail, with reference to FIGS. 3 to 11. The dust filter 119 has at least one side symmetric with respect to a certain symmetry axis, and is a glass plate (optical element) of a polygonal plate as a whole (a square plate, in this embodiment). At least, the area spreading as prescribed from the position obtaining a maximum vibrational amplitude to the radial direction forms a transparent part. Alternatively, the dust filter 119 may be D-shaped, formed by cutting a part of a circular plate, thus defining one side. Still alternatively, it may be formed by cutting a square plate, having two opposite sides accurately cut and having upper and lower sides. The above-mentioned fastening mechanism fastens the dust filter 119, with the transparent part opposed to the front of the LPF 118 and spaced from the LPF 118 by a predetermined distance. To one surface of the dust filter 119 (i.e., back of the filter 119, in this embodiment), the piezoelectric element 120, which is vibrating member, is secured at the upper edge of the filter 119, by means of adhesion using adhesive. A vibrator 170 is formed by arranging the piezoelectric element 120 on the dust filter 119. The vibrator 170 undergoes resonance when a voltage of a prescribed frequency is applied to the piezoelectric element 120. The resonance achieves such bending vibration of a large amplitude, as illustrated in FIGS. 4A to 4C.

As shown in FIG. 3, signal electrodes 171 and 172 are formed on the piezoelectric element 120. Note that the hatched parts shown in FIG. 3 show the shapes of the signal electrodes clearly, not to illustrating the sections thereof. The signal electrode 172 is provided on the back opposing the signal electrode 171, and is bent toward that surface of the piezoelectric element 120, on which the signal electrode 171 is provided. The flex 157 having the above-mentioned conductive pattern is electrically connected to the signal electrode 171 and signal electrode 172. To the signal electrodes 171 and 172, a drive voltage of the prescribed frequency is applied from the dust filter control circuit 121 through flex 157. The drive voltage, thus applied, can cause the dust filter 119 to undergo such a two-dimensional, standing-wave bending vibration as is shown in FIGS. 4A to 4C. The dust filter 119 has a long side length LA, and a short side length LB orthogonal to the long side. (This size notation accords with the size notation used in FIG. 5.) Since the dust filter 119 shown in FIG. 4A is rectangular, it is identical in shape to the "virtual rectangle" according to this invention (described later). (The long side length LA is equal to the side length LF of the virtual rectangle). The bending vibration shown in FIG. 4A is standing wave vibration. In FIG. 4A, the blacker the



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streaks, each indicating a node area **173** of vibration (i.e., area where the vibrational amplitude is small), the smaller the vibrational amplitude is. Note that the meshes shown in FIG. **4A** are division meshes usually used in the final element method.

If the node areas **173** are at short intervals as shown in FIG. **4A** when the vibration speed is high, in-plane vibration (vibration along the surface) will occur in the node areas **173**. This vibration induces a large inertial force in the direction of the in-plane vibration (see mass point **Y2** in FIG. **11**, described later, which moves over the node along an arc around the node, between positions **Y2** and **Y2'**) to the dust at the node areas **173**. If the dust filter **119** is inclined to become parallel to the gravity so that a force may act along the dust receiving surface, the inertial force and the gravity can remove the dust from the node areas **173**.

In FIG. **4A**, the white areas indicate areas where the vibrational amplitude is large. The dust adhering to any white area is removed by the inertial force exerted by the vibration. The dust can be removed from the node areas **173**, too, by producing vibration in another mode with another vibrational amplitude at each node area **173**.

The bending vibrational mode shown in FIG. **4A** is achieved by synthesizing the bending vibration of the X-direction and the bending vibration of the Y-direction. The fundamental state of this synthesis is shown in FIG. **6**. By placing the vibrator **170**, which has two piezoelectric elements **120** and **120'** arranged symmetric to the central axis X of the dust filter **119**, on a member that little attenuates vibration, such as a foamed rubber block, and then made to vibrate freely, a vibrational mode of producing such lattice-shaped node areas **173** as shown in FIG. **6** will be usually attained easily (see Jpn. Pat. Appln. KOKAI Publication No. 2007-228246, identified above). In the front view of FIG. **6**, the broken lines define the node areas **173** (more precisely, the lines indicate the positions where the vibrational amplitude is minimal in the widthwise direction of lines). In this case, a standing wave, bending vibration at wavelength  $\lambda_x$  occurs in the X-direction, and a standing wave, bending vibration at wavelength  $\lambda_y$  occurs in the Y-direction. These standing waves are synthesized. With respect to the origin ( $x=0, y=0$ ), the vibration  $Z(x, y)$  at a given point P ( $x, y$ ) is expressed by Equation 1, as follows:

$$Z(x, y) = A \cdot W_{mn}(x, y) \cdot \cos(\gamma) + A \cdot W_{nm}(x, y) \cdot \sin(\gamma) \quad (1)$$

where A is amplitude (a fixed value here, but actually changing with the vibrational mode or the power supplied to the piezoelectric elements); m and n are positive integers including 0, indicating the order of natural vibration corresponding to the vibrational mode;  $\gamma$  is a given phase angle;

$$W_{mn}(x, y) = \sin\left(n\pi \cdot x + \frac{\pi}{2}\right) \cdot \sin\left(m\pi \cdot y + \frac{\pi}{2}\right);$$

and

$$W_{nm}(x, y) = \sin\left(m\pi \cdot x + \frac{\pi}{2}\right) \cdot \sin\left(n\pi \cdot y + \frac{\pi}{2}\right).$$

Assume that the phase angle  $\gamma$  is 0 ( $\gamma=0$ ). Then, Equation 1 changes to:

$$Z(x, y) = A \cdot W_{mn}(x, y)$$

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-continued

$$= A \cdot \sin\left(\frac{n \cdot \pi \cdot x}{\lambda_x} + \frac{\pi}{2}\right) \cdot \sin\left(\frac{m \cdot \pi \cdot y}{\lambda_y} + \frac{\pi}{2}\right).$$

Further assume that  $\lambda_x = \lambda_y = \lambda = 1$  (x and y are represented by the unit of the wavelength of bending vibration). Then:

$$Z(x, y) = A \cdot W_{mn}(x, y)$$

$$= A \cdot \sin(n \cdot \pi \cdot x + \frac{\pi}{2}) \cdot \sin(m \cdot \pi \cdot y + \frac{\pi}{2}).$$

Here, if the dust filter **119** is shaped a little close to a rectangle, a vibrational mode with a very large vibrational amplitude can be obtained, even if a piezoelectric element is placed along one side as in this embodiment. (The maximum amplitude is at the same level as at the conventional circular dust filter.) At this time, the vibrational mode will be the mode shown FIG. **4A** is obtained. In this vibrational mode, though the dust filter **119** is rectangular, the peak ridges **174** of vibrational amplitude form closed loops around the centroid **119a** of the dust filter **119**. Consequently, a reflected wave coming from a side extending in the X-direction and a reflected wave coming from a side extending in the Y-direction are efficiently combined, forming a standing wave. Here, the dust filter **119** has at least one side symmetric to the virtual axis passing through the centroid **119a**, and the piezoelectric element **120** is arranged along the side, as the centroid **120a** of the piezoelectric element **120** is located on the virtual axis. The center of the closed loop formed by the peak ridges **174** of vibrational amplitude becomes a central vibrating area **175** having maximum vibration speed and vibrational amplitude. The centroid **175a** of the central vibrating area **175** and the centroid **173a** of an area surrounded by the node area **173** having almost no vertical vibrational amplitude against the surface formed in the dust filter **119**, including the centroid **175a** of the central vibrating area **175**, are substantially identical and located on the above virtual axis. However, since the piezoelectric element **120** is arranged along the above one side, the centroid **175a** of the central vibrating area **175** is displaced to the other side arranged opposing to the above one side.

FIG. **7** shows a vibrational mode generated by changing the vibrational frequency of the dust filter **119** of FIG. **4A**. In this vibrational mode, peak ridges **174** of vibrational amplitude arranged continuously and substantially concentrically are formed from one side symmetric to the virtual axis passing through the centroid **119a** of the dust filter **119** toward the other side arranged opposing to the above one side. Here, the center **174a** of the continuous concentric peak ridges **174** is located opposite to the other side across the above one side of the dust filter **119**, and on the above virtual axis. As the centroid **120a** of the piezoelectric element **120** is on the virtual axis, the piezoelectric element **120** is arranged along the above one side. Therefore, the centroid **175a** of the central vibrating area **175** having maximum vibration speed and amplitude is displaced from the centroid **119a** of the dust filter **119** toward the other side arranged opposite to the above one side.

The dust filter **119** of the vibrator **170**, shown in FIG. **4A**, is a glass plate (optical element) having a size of 30.5 mm (X-direction: LA, LF) × 31.5 mm (Y-direction: LB) × 0.65 mm (thickness). The dust filter **119** is rectangular, having long sides LA (30.5 mm, extending in the X-direction) and short sides LB (31.5 mm). Therefore, the dust filter **119** is identical



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to the “virtual rectangle” according to this invention, which has the same area as the dust filter 119. The piezoelectric element 120 is made of lead titanate-zirconate ceramic and have a size of 21 mm (X-direction)×3 mm (Y-direction)×0.8 mm (thickness). The piezoelectric element 120 is adhered with epoxy-based adhesive to the dust filter 119, extending along the upper side of the filter 119 (optical element), respectively. More specifically, the piezoelectric element 120 extends in the X-direction and arranged symmetric in the left-right direction, with respect to the centerline of the dust filter 119 (a virtual axis), which extends in the Y-direction. In this case, the resonance frequency in the vibrational mode of FIG. 4A is in the vicinity of 78 kHz. At the center of the dust filter 119, the central vibrating area 175 having maximal vibration speed and vibrational amplitude can be attained if the dust filter is shaped like a circle in which the rectangular dust filter 119 is inscribed. The vibration-speed ratio, which is the ratio of maximum speed  $V_{max}$  to the speed of vibration perpendicular to the plane of the centroid 175a of the central vibrating area 175, has such a value as shown in FIG. 8, the maximum value of which is 1.000. In the graph of FIG. 8, the line curve pertains to the case where the piezoelectric element 120 is arranged parallel to the long side of the dust filter 119, and the line curve pertains to the case where the element 120 is arranged parallel to the short side of the dust filter 119.

FIG. 9 shows a modification of the vibrator 170. The modified vibrator 170 has a dust filter 119 that is D-shaped, formed by cutting a part of a plate shaped like a disc, thus defining one side. That is, the modified vibrator 170 uses a D-shaped dust filter 119 that has a side symmetric with respect to the symmetry axis extending in the Y-direction. The piezoelectric element 120 is arranged on the surface of the dust filter 119, extending parallel to that side and positioned symmetric with respect to the midpoint of the side (or to a symmetry axis extending in the Y-direction (the virtual axis)). So shaped, the dust filter 119 is more symmetric with respect to its center (regarded as the centroid 119a of the dust filter 119), and can more readily vibrate in a state desirable to the present embodiment. In addition, the dust filter 119 can be smaller than the circular one. Furthermore, since the piezoelectric element 120 arranged parallel to the side, the asymmetry in terms vibration, resulting from the cutting, can be made more symmetric by increasing the rigidity. This helps to render the vibration state more desirable. Note that the long side and short side of the dust filter 119 shown in FIG. 9 are as follows. As shown in the drawing, one of the long sides includes one side symmetric to the axis of symmetry in the Y-direction of the dust filter 119, and the other long side is parallel to the above one side, and is one side of the virtual rectangle 176 which has the same area as the dust filter 119. The each short side orthogonal to these sides is a side of the virtual rectangle 176 which has the same area as the dust filter 119.

FIG. 10 shows another modification of the vibrator 170. This modified vibrator 170 has a dust filter 119 is formed by cutting a circular plate along two parallel lines, forming two parallel sides. That is, the modified vibrator 170 uses a dust filter 119 that has two sides symmetric with respect to the symmetry axis extending in the Y-direction. In this case, actuate piezoelectric element 120 is arranged not on the straight sides, but on the curved parts defining a circle. Since the dust filter 119 is so shaped, the piezoelectric element 120 is arranged, efficiently providing a smaller vibrator 170. Note that the long side and shot side of the dust filter 119 shown in FIG. 10 are the long and short sides of a virtual rectangle 176 which has the same area as the dust filter 119, two opposite sides of which extend along the opposite two sides of the dust filter 119, respectively.

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A method of removing dust will be explained in detail, with reference to FIG. 11. FIG. 11 shows a cross section identical to that shown in FIG. 4B. Assume that the piezoelectric element 120 is polarized in the direction of arrow 177 as shown in FIG. 11. If a voltage of a specific frequency is applied to the piezoelectric element 120 at a certain time  $t_0$ , the vibrator 170 will be deformed as indicated by solid lines. At the mass point Y existing at given position y in the surface of the vibrator 170, the vibration z in the Z-direction is expressed by Equation 2, as follows:

$$z = A \cdot \sin(Y) \cdot \cos(\omega t) \quad (2)$$

where  $\omega$  is the angular velocity of vibration, A is the amplitude of vibration in the Z-direction, and  $Y = 2\pi y/\lambda$  ( $\lambda$ : wavelength of bending vibration).

The Equation 2 represents the standing-wave vibration shown in FIG. 4A. Thus, if  $y = s \cdot \lambda/2$  (here, s is an integer), then  $Y = s\pi$ , and  $\sin(Y) = 0$ . Hence, a node 178, at which the amplitude of vibration in the Z-direction is zero irrespective of time, exists for every  $\pi/2$ . This is standing-wave vibration. The state indicated by broken lines in FIG. 11 takes place if  $t = k\pi/\omega$  (k is odd), where the vibration assumes a phase opposite to the phase at time  $t_0$ .

Vibration  $z(Y_1)$  at point  $Y_1$  on the dust filter 119 is located at an antinode 179 of standing wave, bending vibration. Hence, the vibration in the Z-direction has amplitude A, as expressed in Equation 3, as follows:

$$z(Y_1) = A \cdot \cos(\omega t) \quad (3)$$

If Equation 3 is differentiated with time, the vibration speed  $Vz(Y_1)$  at point  $Y_1$  is expressed by Equation 4, below, because  $\omega = 2\pi f$ , where f is the frequency of vibration:

$$Vz(Y_1) = \frac{d(z(Y_1))}{dt} = -2\pi f \cdot A \cdot \sin(\omega t) \quad (4)$$

If Equation 4 is differentiated with time, vibration acceleration  $\alpha z(Y_1)$  is expressed by Equation 5, as follows:

$$\alpha z(Y_1) = \frac{d(Vz(Y_1))}{dt} = -4\pi^2 f^2 \cdot A \cdot \cos(\omega t) \quad (5)$$

Therefore, the dust 180 adhering at point  $Y_1$  receives the acceleration of Equation 5. The inertial force Fk the dust 180 receives at this time is given by Equation 6, as follows:

$$Fk = \alpha z(Y_1) \cdot M = -4\pi^2 f^2 \cdot A \cdot \cos(\omega t) \cdot M \quad (6)$$

where M is the mass of the dust 180.

As can be seen from Equation 6, the inertial force Fk increases as frequency f is raised, in proportion to the square of f. However, the inertial force cannot be increased if amplitude A is small, no matter how much frequency f is raised. Generally, kinetic energy of vibration can be produced, but in a limited value, if the piezoelectric element 120 that produces the kinetic energy has the same size. Therefore, if the frequency is raise the same vibrational mode, vibrational amplitude A will change in inverse proportion to the square of frequency f. Even if the resonance frequency is raised to achieve a higher-order resonance mode, the vibrational frequency will fall, not increasing the vibration speed or the vibration acceleration. Rather, if the frequency is raised, ideal resonance will hardly be accomplished, and the loss of vibrational energy will increase, inevitably decreasing the vibration acceleration. That is, the mode cannot attain large ampli-



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tude if the vibration is produced in a resonance mode that uses high frequency only. The dust removal efficiency will be much impaired.

Although the dust filter **119** is rectangular, the peak ridges **174** of vibrational amplitude form closed loops around the optical axis in the vibrational mode of the embodiment, which is shown in FIG. 4A. In the vibrational mode of the embodiment, which is shown in FIG. 7, the peak ridges **174** of vibrational amplitude form curves surrounding the midpoint of each side. The wave reflected from the side extending in the X-direction and the wave reflected from the side extending in the Y-direction are efficiently synthesized, forming a standing wave.

The shape and size of the dust filter **119** greatly contribute to efficient generation of this synthesized standing wave. As seen from FIG. 8, it is better to set the aspect ratio (short side/long side), i.e., ratio of the length of the short sides orthogonal to the length of the long sides of the dust filter **119**, to a value smaller than 1, than to 1 (to make the dust filter **119** square). If the aspect ratio is smaller than 1, the speed of vibration at the center of the dust filter **119**, in the Z-direction will be higher (the vibration speed ratio is 0.7 or more), no matter whether only one piezoelectric element **120** is arranged. However, the centroid **175a** of the central vibrating area **175** is displaced from the centroid **119a** of the dust filter **119**. In FIG. 8, the vibration speed ratio ( $V/V_{max}$ ) of the vibration speed  $V$  to the maximum vibration speed  $V_{max}$  possible in this central vibrating area **175** is plotted on the ordinate. The maximum aspect ratio (i.e., short side/long side) is, of course, 1. At the aspect ratio of 0.9 or less, the vibration speed abruptly decreases. Therefore, the dust filter **119** preferably has an aspect ratio (short side/long side) of 0.9 to 1, but less than 1. The line curve of "short-side arrangement" in FIG. 8 indicates vibration speed ratio, which is smaller than the vibration speed ratio of the line curve of "long-side arrangement" which the piezoelectric element **120** is arranged parallel to the long side of the dust filter **119**. It is therefore advisable to arrange the piezoelectric element **120** at the long side of the dust filter **119**, not at the short side thereof. If the element **120** is so arranged, the vibration speed ratio will increase to achieve a high dust removal ability.

In vibration wherein the peak ridges **174** of vibrational amplitude form closed loops around the optical axis or the peak ridges **174** form curves surrounding the midpoint of each side, the dust filter **119** can undergo vibration of amplitude a similar to that of concentric vibration that may occur if the dust filter **119** has a disc shape. In any vibrational mode in which the amplitude is simply parallel to the side, the vibration acceleration is only 10% or more of the acceleration achieved in this embodiment.

In the vibration wherein the peak ridges **174** of vibrational amplitude form closed loops or curves surrounding the midpoint of each side, the vibrational amplitude is the largest at the center of the vibrator **170** and small at the closed loop or the curve at circumferential edges. Thus, the dust removal capability is maximal at the center of the image. If the center of the vibrator **170** is aligned with the optical axis, the shadow of dust **180** will not appear in the center part of the image, which has high image quality. This is an advantage.

In the vibration node areas **173**, which exist in the focusing-beam passing area **149**, the nodes **178** may be changed in position by changing the drive frequencies of the piezoelectric element **120**. Then, the element **120** resonates in a different vibrational mode, whereby the dust can be removed, of course.

A vibration state that is attained if the piezoelectric element **120** is driven at a frequency near the resonance frequency will

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be described with reference to FIGS. 12A and 12B. FIG. 12A shows an equivalent circuit that drives the piezoelectric element **120** at a frequency near the resonance frequency. In FIG. 12A,  $C_0$  is the electrostatic capacitance attained as long as the piezoelectric element **120** remain connected in parallel, and  $L$ ,  $C$  and  $R$  are the values of a coil, capacitor and resistor that constitute an electric circuit equivalent to the mechanical vibration of the vibrator **170**. Naturally, these values change with the frequency.

When the frequency changes to resonance frequency  $f_0$ ,  $L$  and  $C$  achieve resonance as is illustrated in FIG. 12B. As the frequency is gradually raised toward the resonance frequency from the value at which no resonance takes place, the vibration phase of the vibrator **170** changes with respect to the phase of vibration of the piezoelectric element **120**. When the resonance starts, the phase reaches  $\pi/2$ . As the frequency is further raised, the phase reaches  $\pi$ . If the frequency is raised even farther, the phase starts decreasing. When the frequency comes out of the resonance region, the phase becomes equal to the phase where no resonance undergoes at low frequencies. In the actual situation, however, the vibration state does not become ideal. The phase does not change to  $n$  in some cases. Nonetheless, the drive frequency can be set to the resonance frequency.

Support areas **180** existing at the four corners, as shown in FIG. 4A and FIG. 7, are areas in which virtually no vibration takes place. Therefore, these parts are pushed in the Z-direction, thereby pushing the dust filter **119** through the cushion members **152** and **153** made of vibration-attenuating material such as rubber. So held, the dust filter **119** can be reliably pushed without attenuating the vibration. In other words, the cushion members **152** and **153** made of rubber or the like scarcely attenuate the in-plane vibration, because they allow the dust filter **119** to vibrate in plane.

On the other hand, the seal **156** which receives the dust filter **119** must be provided in the area having vibrational amplitude, too. In the vibrational mode of the present invention, the peripheral vibrational amplitude is small. In view of this, the dust filter **119** is supported, at circumferential edge, by the lip-shaped part of the seal **156**, thereby applying no large force in the direction of bending vibrational amplitude. Therefore, the seal **156** attenuates, but very little, the vibration whose amplitude is inherently small. As shown in FIG. 4A and FIG. 7, as many seal-contact parts **182** as possible contact the node areas **173** in which the vibrational amplitude is small. This further reduces the attenuation of vibration.

The proscribed frequency at which to vibrate the piezoelectric element **120** is determined by the shape and dimensions of the dust filter **119** and piezoelectric element **120** forming the oscillator **170**, and the materials and supported states of them. Therefore, it is desirable to measure the temperature of the vibrator **170** and to consider the change in the natural frequency of the vibrator **170**, before the vibrator **170** is used. A temperature sensor (not shown) is therefore connected to a temperature measuring circuit (not shown), in the digital camera **10**. The value by which to correct the vibrational frequency of the vibrator **170** in accordance the temperature detected by the temperature sensor is stored in the nonvolatile memory **128**. Then, the measured temperature and the correction value are read into the Bucom **101**. The Bucom **101** calculates a drive frequency, which is used as drive frequency of the dust filter control circuit **121**. Thus, vibration can be produced, which is efficient with respect to temperature changes, as well.

The dust filter control circuit **121** of the digital camera **10** according to this invention will be described below, with reference to FIGS. 13 and 14. The dust filter control circuit



121 has such a configuration as shown in FIG. 13. The components of the dust filter control circuit 121 produce signals (Sig1 to Sig4) such waveforms as shown in the timing chart of FIG. 14. These signals will control the dust filter 119, as will be described below.

More specifically, as shown in FIG. 13, the dust filter control circuit 121 comprises a N-scale counter 183, a half-frequency dividing circuit 184, an inverter 185, a plurality of MOS transistors  $Q_{00}$ ,  $Q_{01}$  and  $Q_{02}$ , a transformer 186, and a resistor  $R_{00}$ .

The dust filter control circuit 121 is so configured that a signal (Sig4) of the prescribed frequency is produced at the secondary winding of the transformer 186 when MOS transistors  $Q_{01}$  and  $Q_{02}$  connected to the primary winding of the transformer 186 are turned on and off. The signal of the prescribed frequency drives the piezoelectric element 120, thereby causing the vibrator 170, to which the dust filter 119 is secured, to produce a resonance standing wave.

The Bucom 101 has two output ports P\_PwCont and D\_NCnt provided as control ports, and a clock generator 187. The output ports P\_PwCont and D\_NCnt and the clock generator 187 cooperate to control the dust filter control circuit 121 as follows. The clock generator 187 outputs a pulse signal (basic clock signal) having a frequency much higher than the frequency of the signal that will be supplied to the piezoelectric element 120. This output signal is signal Sig1 that has the waveform shown in the timing chart of FIG. 14. The basic clock signal is input to the N-scale counter 183.

The N-scale counter 183 counts the pulses of the pulse signal. Every time the count reaches a prescribed value "N," the N-scale counter 183 produces a count-end pulse signal. Thus, the basic clock signal is frequency-divided by N. The signal the N-scale counter 183 outputs is signal Sig2 that has the waveform shown in the timing chart of FIG. 14.

The pulse signal produced by means of frequency division does not have a duty ratio of 1:1. The pulse signal is supplied to the half-frequency dividing circuit 184. The half-frequency dividing circuit 184 changes the duty ratio of the pulse signal to 1:1. The pulse signal, thus changed in terms of duty ratio, corresponds to signal Sig3 that has the waveform shown in the timing chart of FIG. 14.

While the pulse signal, thus changed in duty ratio, is high, MOS transistor  $Q_{01}$  to which this signal has been input is turned on. In the meantime, the pulse signal is supplied via the inverter 185 to MOS transistor  $Q_{02}$ . Therefore, while the pulse signal (signal Sig3) is low state, MOS transistor  $Q_{02}$  to which this signal has been input is turned on. Thus, the transistors  $Q_{01}$  and  $Q_{02}$ , both connected to the primary winding of the transformer 186, are alternately turned on. As a result, a signal Sig4 of such frequency as shown in FIG. 14 is produced in the secondary winding of the transformer 186.

The winding ratio of the transformer 186 is determined by the output voltage of the power-supply circuit 135 and the voltage needed to drive the piezoelectric element 120. Note that the resistor  $F_{00}$  is provided to prevent an excessive current from flowing in the transformer 186.

In order to drive the piezoelectric element 120, MOS transistor  $Q_{00}$  must be on, and a voltage must be applied from the power-supply circuit 135 to the center tap of the transformer 186. In this case, MOS transistor  $Q_{00}$  is turned on or off via the output port P\_PwCont of the Bucom 101. Value "N" can be set to the N-scale counter 183 from the output port D\_NCnt of the Bucom 101. Thus, the Bucom 101 can change the drive frequency for the piezoelectric element 120, by appropriately controlling value "N."

frequency can be calculated by using Equation 7, as follows:

$$f_{drv} = \frac{f_{pls}}{2N} \quad (7)$$

where N is the value set to the N-scale counter 183,  $f_{pls}$  the frequency of the pulse output from the clock generator 187, and  $f_{drv}$  is the frequency of the signal supplied to the piezoelectric element 120.

The calculation based on Equation 7 is performed by the CPU (control unit) of the Bucom 101.

If the dust filter 119 is vibrated at a frequency in the ultrasonic region (i.e., 20 kHz or more), the operating state of the dust filter 119 cannot be aurally discriminated, because most people cannot hear sound falling outside the range of about 20 to 20,000 Hz. This is why the operation display LCD 129 or the operation display LED 130 has a display unit for showing how the dust filter 119 is operating, to the operator of the digital camera 10. More precisely, in the digital camera 10, the vibrating members (piezoelectric element 120) imparts vibration to the dust-screening member (dust filter 119) that is arranged in front of the CCD 117, can be vibrated and can transmit light. In the digital camera 10, the display unit operated in interlock with the vibrating member drive circuit (i.e., dust filter control circuit 121), thus informing how the dust filter 119 is operating (later described in detail).

To explain the above-described characteristics in detail, the control the Bucom 101 performs will be described with reference to FIGS. 15A to 19. FIGS. 15A and 15B show the flowchart that relates to the control program, which the Bucom 101 starts executing when the power switch (not shown) provided on the body unit 100 of the camera 10 is turned on.

First, a process is performed to activate the digital camera 10 (Step S101). That is, the Bucom 101 control the power-supply circuit 135. So controlled, the power-supply circuit 135 supplies power to the other circuit units of the digital camera 10. Further, the Bucom 101 initializes the circuit components.

Next, the Bucom 101 calls a sub-routine "silent vibration," vibrating the dust filter 119, making no sound (that is, at a frequency falling outside the audible range) (Step S102). The "audible range" ranges from about 200 to 20,000 Hz, because most people can hear sound falling within this range.

Steps S103 to S124, which follow, make a group of steps that is cyclically repeated. That is, the Bucom 101 first detects whether an accessory has been attached to, or detached from, the digital camera 10 (Step S103). Whether the lens unit 200 (i.e., one of accessories), for example, has been attached to the body unit 100 is detected. This detection, e.g., attaching or detaching of the lens unit 200, is performed as the Bucom 101 communicates with the Lucom 201.

If a specific accessory is detected to have been attached to the body unit 100 (YES in Step S104), the Bucom 101 calls a subroutine "silent vibration" and causes the dust filter 119 to vibrate silently (Step S105).

While an accessory, particularly the lens unit 200, remains not attached to the body unit 100 that is the camera body, dust is likely to adhere to each lens, the dust filter 119, and the like. It is therefore desirable to perform an operation of removing dust at the time when it is detected that the lens unit 200 is attached to the body unit 100. It is highly possible that dust adheres as the outer air circulates in the body unit 100 at the time a lens is exchanged with another. It is therefore advisable to remove dust when a lens is exchange with another. Then, it is determined that photography will be immediately performed, and the operation goes to Step S106.



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If a specific accessory is not detected to have been attached to the body unit **100** (NO in Step S104), the Bucom **101** goes to the next step, i.e., Step S106.

In Step S106, the Bucom **101** detects the state of a specific operation switch that the digital camera **10** has.

That is, the Bucom **101** determines whether the first release switch (not shown), which is a release switch, has been operated from the on/off state of the switch (Step S107). The Bucom **101** reads the state. If the first release switch has not been turned on for a predetermined time, the Bucom **101** discriminates the state of the power switch (Step S108). If the power switch is on, the Bucom **101** returns to Step S103. If the power switch is off, the Bucom **101** performs an end-operation (e.g., sleep).

On the other hand, the first release switch may be found to have been turned on in Step S107. In this case, the Bucom **101** acquires the luminance data about the object from the acquired image from the image process controller **126**, and calculates from this data an exposure time (Tv value) and a diaphragm value (Av value) that are optimal for the image acquisition unit **116** and lens unit **200**, respectively (Step S109).

Thereafter, the Bucom **101** detects the contrast of the acquired image (step S110). The Bucom **101** then determines whether the detected contrast falls within a tolerance range (step S111). If the contrast does not fall within the tolerance range, the Bucom **101** drives the photographic lens **202** (step S112) and returns to step S103.

On the other hand, the contrast may fall within the tolerance range. In this case, the Bucom **101** calls the subroutine “silent vibration” and causes the dust filter **119** to vibrate silently (step S113).

Further, the Bucom **101** determines whether the second release switch (not shown), which is another release switch, has been operated (Step S114). If the second release switch is on, the Bucom **101** goes to Step S115 and starts the prescribed photographic operation (later described in detail). If the second release switch is off, the Bucom **101** returns to Step S108.

During the image acquisition operation, the electronic image acquisition is controlled for a time that corresponds to the preset time for exposure (i.e., exposure time), as in ordinary photography.

As the above-mentioned photographic operation, Steps S115 to S121 are performed in a prescribed order to photograph an object. First, the Bucom **101** transmits the Av value to the Lucom **201**, instructing the Lucom **201** to drive the diaphragm **203** (Step S113). Then, the Bucom **101** causes the front curtain of the shutter **108** to start running, performing open control (Step S117). Further, the Bucom **101** makes the image process controller **126** perform “image acquisition operation” (Step S118). When the exposure to the CCD **117** (i.e., photography) for the time corresponding to the Tv value ends, the Bucom **101** causes the rear curtain of the shutter **108** to start running, achieving CLOSE control (Step S119). Then, the Bucom **101** cocks the shutter **108** (Step S120).

Then, the Bucom **101** instructs the Lucom **210** to move the diaphragm **203** back to the open position (Step S121). Thus, a sequence of image acquisition steps is terminated.

Next, the Bucom **101** determines whether the recording medium **127** is attached to the body unit **100** (Step S122). If the recording medium **127** is not attached, the Bucom **101** displays an alarm (Step S123). The Bucom **101** then returns to Step S103 and repeats a similar sequence of steps.

If the recording medium **127** is attached, the Bucom **101** instructs the image process controller **126** to record the image data acquired by photography, in the recording medium **127**

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(Step S124). When the image data is completely recorded, the Bucom **101** returns to Step S103 again and repeats a similar sequence of steps.

In regard to the detailed relation between the vibration state and the displaying state will be explained in detail, the sequence of controlling the “silent vibration” subroutine will be explained with reference to FIGS. **16** to **19**. The term “vibration state” means the state of the vibration induced by the piezoelectric element **120**, i.e., vibrating members. FIG. **20** shows the form of a resonance-frequency wave that is continuously supplied to the vibrating members during silent vibration. The subroutine of FIG. **16**, i.e., “silent vibration,” and the subroutine of FIGS. **17** to **19**, i.e., “display process” are routines for accomplishing vibration exclusively for dust from the dust filter **119**. Vibrational frequency  $f_0$  is set to a value close to the resonance frequency of the dust filter **119**. In the vibrational mode of FIG. **4A**, for example, the vibrational frequency is 78 kHz, higher than at least 20 kHz, and produces sound not audible to the user.

As shown in FIG. **16**, when the “silent vibration” is called, the Bucom **101** first reads the data representing the drive time (Toscf0) and drive frequency (resonance frequency: Noscfo) from the data stored in a specific area of the nonvolatile memory **128** (Step S201). At this timing, the Bucom **101** causes the display unit provided in the operation display LCD **129** or operation display LED **130** to turn on the vibrational mode display, as shown in FIG. **17** (Step S301). The Bucom **101** then determines whether a predetermined time has passed (Step S302). If the predetermined time has not passed, the Bucom **101** makes the display unit keep turning on the vibrational mode display. Upon lapse of the predetermined time, the Bucom **101** turns off the displaying of vibrational mode display (Step S303).

Next, the Bucom **101** outputs the drive frequency Noscfo from the output port D\_NCnt to the N-scale counter **183** of the dust filter control circuit **121** (Step S202).

In the following steps S203 to S205, the dust is removed as will be described below. First, the Bucom **101** sets the output port P\_PwCnt to High, thereby starting the dust removal (Step S203). At this timing, the Bucom **101** starts displaying the vibrating operation as shown in FIG. **18** (Step S311). The Bucom **101** then determines whether or not the predetermined time has passed (Step S312). If the predetermined time has not passed, the Bucom **101** keeps displaying the vibrating operation. Upon lapse of the predetermined time, the Bucom **101** stops displaying of the vibrating operation (Step S313). The display of the vibrating operation, at this time, changes as the time passes or as the dust is removed (how t changes is not shown, though). The predetermined time is almost equal to Toscf0, i.e., the time for which the vibration (later described) continues.

If the output port P\_PwCnt is set to High in Step S203, the piezoelectric element **120** vibrates the dust filter **119** at the prescribed vibrational frequency (Noscfo), removing the dust **180** from the surface of the dust filter **119**. At the same time the dust **180** is removed from the surface of the dust filter **119**, air is vibrated, producing an ultrasonic wave. The vibration at the drive frequency Noscfo, however, does not make sound audible to most people. Hence, the user hears nothing. The Bucom **101** waits for the predetermined time Toscf0, while the dust filter **119** remains vibrated (Step S204). Upon lapse of the predetermined time Toscf0, the Bucom **101** sets the output port P\_PwCnt to Low, stopping the dust removal operation (Step S205). At this timing, the Bucom **101** turns on the display unit, whereby the displaying of the vibration-end display is turned on (Step S321). When the Bucom **101** determines (in Step S322) that the predetermined time has passed,



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the displaying of the vibration-end display is turned off (Step S323). The Bucom 101 then returns to the step next to the step in which the “silent vibration” is called.

The vibrational frequency  $f_0$  (i.e., resonance frequency Noscfo) and the drive time (Toscf0) used in this subroutine define such a waveform as shown in the graph of FIG. 20. As can be seen from this waveform, constant vibration ( $f_0=78$  kHz) continues for a time (i.e., Toscf0) that is long enough to accomplish the dust removal.

That is, the vibrational mode adjusts the resonance frequency applied to the vibrating member, controlling the dust removal.

As described above, according to the embodiment, the compact vibrator 170 whose vibrational amplitude can be increased is obtained by providing the piezoelectric element 120 at one of the ends of the dust 119.

## Second Embodiment

The subroutine “silent vibration” called in the camera sequence (main routine) that the Bucom performs in a digital camera that is a second embodiment of the image equipment according to this invention will be described with reference to FIG. 21. FIG. 21 illustrates a modification of the subroutine “silent vibration” shown in FIG. 16. The second embodiment differs from the first embodiment in the operating mode of the dust filter 119. In the first embodiment, the dust filter 119 is driven at a fixed frequency, i.e., frequency  $f_0$ , producing a standing wave. By contrast, in the second embodiment, the drive frequency is gradually changed, thereby achieving large-amplitude vibration at various frequencies including the resonance frequency, without strictly controlling the drive frequency.

If the aspect ratio shown in FIG. 8 has changed from the design value of 0.9, during the manufacture, the vibrational mode will greatly change (that is, the vibration speed ratio will abruptly change). Therefore, a precise resonance frequency must be set in each product and the piezoelectric element 120 must be driven at the frequency so set. This is because the vibration speed will further decrease if the piezoelectric element is driven at any frequency other than the resonance frequency. An extremely simple circuit configuration can, nonetheless, drive the piezoelectric element precisely at the resonance frequency if the frequency is controlled as in the second embodiment. A method of control can therefore be achieved to eliminate any difference in resonance frequency between the products.

First, the Bucom 101 reads the data representing the drive time (Toscf0), drive-start frequency (Noscfs), frequency change value ( $\Delta f$ ) and drive-end frequency (Noscft), from the data stored in a specific area of the nonvolatile memory 128 (Step S211). At this timing, the Bucom 101 causes the display unit to display the vibrational mode as shown in FIG. 17, in the same way as in the first embodiment.

Next, the Bucom 101 sets the drive-start frequency (Noscfs) as drive frequency (Noscfs) (Step S212). The Bucom 101 then outputs the drive frequency (Noscfs) from the output port D\_NCnt to the N-scale counter 183 of the dust filter control circuit 121 (Step S213).

In the following steps S214 et seq., the dust is removed as will be described below. First, the dust removal is started. At this time, the display of the vibrating operation is performed as shown in FIG. 18, as in the first embodiment.

First, the Bucom 101 sets the output port P\_PwCont to High, to achieve dust removal (Step S214). The piezoelectric element 120 vibrates the dust 119 at the prescribed vibrational frequency (Noscfs), producing standing wave of a small

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amplitude at the dust filter 119. The dust 180 cannot be removed from the surface of the dust filter 119, because the vibrational amplitude is small. This vibration continues for the drive time (Toscf0) (Step S215). Upon lapse of this drive time (Toscf0), the Bucom 101 determines whether the drive frequency (Noscfs) is equal to the drive-end frequency (Noscft) (Step S216). If the drive frequency is not equal to the drive-end frequency (NO in Step S216), the Bucom 101 adds the frequency change value ( $\Delta f$ ) to the drive frequency (Noscfs), and sets the sum to the drive frequency (Noscfs) (Step S217). Then, the Bucom 101 repeats the sequence of Steps S212 to S216.

If the drive frequency (Noscfs) is equal to the drive-end frequency (Noscft) (YES in Step S216), the Bucom 101 sets the output port P\_PwCont to Low, stopping the vibration of the piezoelectric element 120 (Step S218), thereby terminating the “silent vibration.” At this point, the display of vibration-end is performed as shown in FIG. 19, as in the first embodiment.

As the frequency is gradually changed as described above, the amplitude of the standing wave increases. In view of this, the drive-start frequency (Noscfs), the frequency change value ( $\Delta f$ ) and the drive-end frequency (Noscft) are set so that the resonance frequency of the standing wave may be surpassed. As a result, a standing wave of small vibrational amplitude is produced at the dust filter 119. The standing wave can thereby controlled, such that its vibrational amplitude gradually increases until it becomes resonance vibration, and then decreases thereafter. If the vibrational amplitude (corresponding to vibration speed) is larger than a prescribed value, the dust 180 can be removed. In other words, the dust 180 can be removed while the vibrational frequency remains in a prescribed range. This range is broad in the present embodiment, because the vibrational amplitude is large during the resonance.

If the difference between the drive-start frequency (Noscfs) and the drive-end frequency (Noscft) is large, the fluctuation of the resonance frequency, due to the temperature of the vibrator 170 or to the deviation in characteristic change of the vibrator 170, during the manufacture, can be absorbed. Hence, the dust 180 can be reliably removed from the dust filter 119, by using an extremely simple circuit configuration.

## Third Embodiment

In the first and second embodiments described above, a liquid crystal monitor is used as a viewfinder. It is of course also possible to use a single-lens reflex camera having an optical viewfinder.

FIG. 22 is a block diagram schematically showing an exemplary system configuration, mainly electrical, of a lens-exchangeable, single-lens reflex electronic camera (digital camera) as a third embodiment of the image equipment according to the invention. Here, the same reference numbers are given to the same parts as those of the digital camera shown in FIG. 1 according to the first embodiment, and explanation thereof is omitted. Only different parts are explained.

In the body unit 100 of the digital camera 10, in addition to the components in the first embodiment, for example, a pentaprism 188, a screen 189, a quick return mirror 190, an eyepiece lens 191, a sub-mirror 192, an AF sensor unit 193, an AF sensor drive circuit 194, a mirror drive mechanism 195, a photometry sensor 196, and a photometry circuit 197 are arranged as shown in FIG. 22. The pentaprism 188, screen 189, quick return mirror 190, eyepiece lens 191, and sub-mirror 192 are single-lens reflex components that constitute an optical system. The AF sensor unit 193 receives a reflected



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light flux from the sub-mirror **192**, and detects the degree of defocusing. The AF sensor drive circuit **194** controls and drives the AF sensor unit **193**. The mirror drive mechanism **195** controls and drives the quick return mirror **190**. The photometry sensor **196** detects the light beam coming from the penta-prism **103**. The photometry circuit **197** performs a photometry process on the basis of the light beam detected by the photometry sensor **196**.

The mirror drive mechanism **195** is a mechanism that drives the quick return mirror **190** between an up position and a down position. While the quick return mirror **190** stays at the down position, the light beam coming from the photographic lens **202** is split into two beams. One beam is guided to the AF sensor unit **193**, and the other beam is guided to the penta-prism **188**. The output from the AF sensor provided in the AS sensor unit **193** is transmitted via the AF sensor drive circuit **194** to the Bucom **101**. The Bucom **101** performs the distance measuring of the known type. In the meantime, a part of the light beam, which has passed through the penta-prism **188**, is guided to the photometry sensor **196** that is electrically connected to the photometry circuit **197**. The photometry circuit **115** performs photometry of the known type, on the basis of the amount of light detected by the photometry sensor **196**.

In the operation of the single-lens reflex digital camera **10** configured as described above, the following points are different from the camera sequence (main routine) performed by the Bucom **101** shown in FIGS. **15A** and **15B**.

As described hereinbefore, when the first release switch is found to have been turned on in step **S107**, an exposure time (Tv value) of the image acquisition unit **116** and a diaphragm value (Av value) of the lens unit **200** are calculated as step **S109**. In the first embodiment, this calculation is executed based on the luminance data about the object obtained from the acquired image sent from the image process controller **126**. In the third embodiment, the calculation is executed based on the luminance data about the object sent from the photometry circuit **197**.

In the first embodiment, the contrast of acquired image is detected in step **S110**, and whether the detected contrast falls within a tolerance range is determined in step **S111**. On the other hand, in the third embodiment, in step **S110**, the detected data of the AF sensor unit **193** is obtained through the AF sensor drive circuit **194**, and the degree of defocusing is calculated based on this data. In step **S111**, whether the calculated degree of defocusing falls within a tolerance range. If No in this step, step **S112** is carried out, and the photographic lens **202** is driven and controlled. If the degree of defocusing falls within the tolerance range, step **S113** is carried out, and a sub-routine "silent vibration" is called.

As for the photographic operation executed when the second release switch is turned on in step **S114**, after the diaphragm **203** is driven in step **S115**, the following operation is performed in this embodiment before the opening of the shutter **108** is controlled. Specifically, the Bucom **101** moves the quick return mirror **190** to the up position. Further, in this embodiment, in step **S120**, the shutter **108** is charged, and it is necessary to move the quick return mirror **190** to the down position.

The present invention has been explained, describing some embodiments. Nonetheless, this invention is not limited to the embodiments described above. Various changes and modifications can, of course, be made within the scope and spirit of the invention.

For example, a mechanism that applies an air flow or a mechanism that has a wipe may be used in combination with

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the dust removal mechanism having the vibrating member, in order to remove the dust **180** from the dust filter **119**.

In the embodiments described above, the CCD **117** is used as an image sensor element. It is of course permitted to use a CMOS and other image sensor. Further, in the embodiments, the vibrating members are piezoelectric elements. The piezoelectric elements may be replaced by electrostrictive members or super magnetostrictive elements.

In order to remove dust **180** more efficiently from the member vibrated, the member may be coated with an indium-tin oxide (ITO) film, which is a transparent conductive film, indium-zinc film, poly 3,4-ethylenedioxy thiophene film, surfactant agent film that is a hygroscopic anti-electrostatic film, siloxane-based film, or the like. In this case, the frequency, the drive time, etc., all related to the vibration, are set to values that accord with the material of the film.

Moreover, the optical LPF **118**, described as one embodiment of the invention, may be replaced by a plurality of optical LPFs that exhibit birefringence. Of these optical LPFs, the optical LPF located closest the object of photography may be used as a dust-screening member (i.e., a subject to be vibrated), in place of the dust filter **119** shown in FIG. **2A**.

Further, a camera may does not have the optical LPF **118** of FIG. **2A** described as one embodiment of the invention, and the dust filter **119** may be used as an optical element such as an optical LPF, an infrared-beam filter, a deflection filter, or a half mirror.

Furthermore, the camera may not have the optical LPF **118**, and the dust filter **119** may be replaced by the protection glass plate **142** shown in FIG. **2A**. In this case, the protection glass plate **142** and the CCD chip **136** remain free of dust and moisture, and the structure of FIG. **2A** that supports and yet vibrates the dust filter **119** may be used to support and vibrate the protection glass plate **142**. Needless to say, the protection glass plate **142** may be used as an optical element such as an optical LPF, an infrared-beam filter, a deflection filter, or a half mirror.

The image equipment according to this invention is not limited to the image acquisition apparatus (digital camera) exemplified above. This invention can be applied to any other apparatus that needs a dust removal function. The invention can be practiced in the form of various modifications, if necessary. More specifically, a dust moving mechanism according to this invention may be arranged between the display element and the light source or image projecting lens in an image projector.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, and representative devices shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. A vibrating device comprising:

a dust-screening member which is shaped like a plate as a whole, and which has at least one side that is symmetric with respect to a virtual axis on a surface of the dust-screening member;

a vibrating member which is adjacent to one side of the dust-screening member and is arranged on the surface along said one side of the dust-screening member, and which is configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to the surface of the dust-screening member; and

a drive unit configured to drive the vibrating member to produce the vibration, such that peak ridges of the vibra-



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tion having the vibrational amplitude perpendicular to the surface of the dust-screening member form a closed loop, and an area including a center of the closed loop is surrounded by a node area having almost no vibrational amplitude perpendicular to the surface of the dust-screening member, on the surface of the dust-screening member.

2. The device according to claim 1, wherein the dust-screening member has a virtual rectangle having a same area as the surface of the dust-screening member, and

wherein the surface of the dust-screening member has such a shape that a ratio of a length of a short side to a length of a long side of the virtual rectangle of the dust-screening member is not less than 0.9 and is less than 1, wherein the long side of the virtual rectangle of the dust-screening member corresponds to the one side of the dust-screening member along which the vibrating member is arranged.

3. The device according to claim 1, wherein the center of the closed loop and a center of the node area including the center of the closed loop are located on the virtual axis.

4. The device according to claim 1, wherein:  
the vibrating member includes a piezoelectric element, and the drive unit is configured to supply a frequency signal changing at every predetermined deviation frequency, including a frequency signal of a frequency corresponding to dimensions and material of the dust-screening member, to the piezoelectric element at every predetermined time.

5. The device according to claim 1, wherein:  
only one vibrating member is arranged on the surface of the dust-screening member, and  
a position at which the vibrating member is arranged is a position adjacent to only one of long sides of the dust-screening member.

6. An image equipment comprising:  
an image forming element having an image surface on which an optical image is formed;  
a dust-screening member which is shaped like a plate as a whole, has at least one side that is symmetric with respect to a virtual axis on a surface of the dust-screening member, and has a transparent area spread to a certain width, facing the image surface and spaced therefrom by a predetermined distance;

a vibrating member which is adjacent to one side of the dust-screening member and is arranged on the surface of the dust-screening member along said one side, and which is configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to a surface of the dust-screening member;  
a drive unit configured to drive the vibrating member; and  
a sealing structure configured to seal an area formed between the image forming element and the dust-screening member, at circumferential edges of the image forming element and dust-screening member,

wherein the drive unit drives the vibrating member to produce the vibration, such that peak ridges of the vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member form a closed loop, and an area including a center of the closed loop is surrounded by a node area having almost no vibrational amplitude perpendicular to the surface of the dust-screening member, on the surface of the dust-screening member outside of the sealing structure.

7. The equipment according to claim 6, wherein the sealing structure includes:

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a holder arranged so as to achieve airtight sealing between the image forming element and the dust-screening member; and

a support member configured to secure the dust-screening member to the holder, the support member being supported in a node region that has almost no vibrational amplitude perpendicular to the surface of the dust-screening member.

8. The device according to claim 6, wherein:

the vibrating member includes a piezoelectric element, and the drive unit is configured to supply a frequency signal changing at every predetermined deviation frequency, including a frequency signal of a frequency corresponding to dimensions and material of the dust-screening member, to the piezoelectric element at every predetermined time.

9. The equipment according to claim 6, wherein:

only one vibrating member is arranged on the surface of the dust-screening member, and

a position at which the vibrating member is arranged is a position adjacent to only one of long sides of the dust-screening member.

10. A vibrating device comprising:

a dust-screening member which is shaped like a plate as a whole, and has at least one side that is symmetric with respect to a virtual axis on a surface of the dust-screening member;

a vibrating member which is adjacent to a first side of the dust-screening member and is arranged on the surface of the dust-screening member along the first side, and which is configured to produce, at the surface, vibration having a vibrational amplitude perpendicular to the surface of the dust-screening member; and

a drive unit configured to drive the vibrating member to produce the vibration, which includes peak ridges of vibration having the vibrational amplitude perpendicular to the surface of the dust-screening member, wherein the peak ridges are located such that parts of the peak ridges are continuously and substantially concentrically located on the surface of the dust-screening member from the first side of the dust-screening member toward a second side opposed to the first side, and such that a center of continuous and substantially concentric locations of the parts of the peak ridges is outside of the dust-screening member at a position opposite to the second side across the first side of the dust screening member.

11. The device according to claim 10, wherein the dust-screening member has a virtual rectangle having a same area as the surface of the dust-screening member, and

wherein the surface of the dust-screening member has such a shape that a ratio of a length of a short side to a length of a long side of the virtual rectangle of the dust-screening member is not less than 0.9 and is less than 1, wherein the long side of the virtual rectangle of the dust-screening member corresponds to the first side of the dust-screening member along which the vibrating member is arranged.

12. The device according to claim 10, wherein the center of the continuous peak ridges and a center of a longitudinal direction of the vibrating member are located on the virtual axis.

13. The device according to claim 10, wherein:  
the vibrating member includes a piezoelectric element, and the drive unit is configured to supply a frequency signal changing at every predetermined deviation frequency, including a frequency signal of a frequency corresponding-

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ing to dimensions and material of the dust-screening member, to the piezoelectric element at every predetermined time.

14. The device according to claim 10, wherein:  
only one vibrating member is arranged on the surface of the dust-screening member, and  
a position at which the vibrating member is arranged is a position adjacent to only one of long sides of the dust-screening member.

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